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ELECTRICITY · ACETYLENE · OIL · GAS

Edited by LEON GASTER

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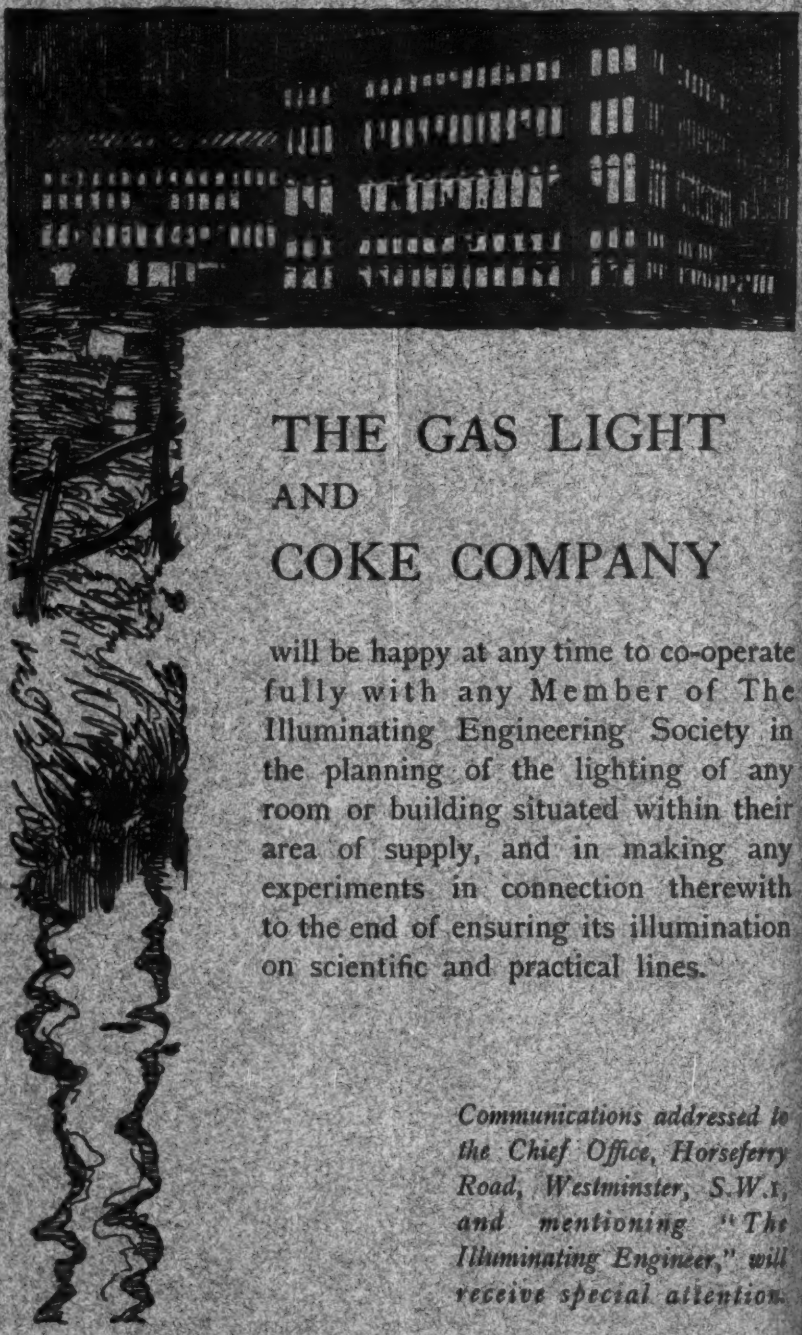
Special Number. Daylight Illumination.

This number contains the paper on **"Window Design and the Predetermination of Daylight Illumination,"** read by Messrs. P. J. and J. M. WALDRAM at the meeting of **The Illuminating Engineering Society** on March 27th, 1923, and the ensuing discussion.

Other matters dealt with include :—

PROBLEMS IN KINEMA STUDIO LIGHTING. MINERS' LAMPS
TRADE NOTES, ETC.



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EDITORIAL.

Window Design and the Predetermination of Daylight Illumination.

The study of daylight illumination, reviewed in the comprehensive paper read by Messrs. P. J. and J. M. Waldram before the Illuminating Engineering Society on March 27th, has passed through several distinct stages. While it has long been a familiar fact that daylight varies greatly at different times in the day and at various periods of the year, it is only within recent years that the variations have been thoroughly mapped out. The authors remark that prior to 1907 there was no illumination-photometer suitable for the measurement of daylight, which may fluctuate from a low value to thousands of foot-candles. In view of the extreme variability of daylight, it might, at first sight, seem almost a hopeless problem to attempt to predetermine natural illumination in a building. Numerical measurements of daylight have, however, taught us much by enabling us to recognise the chief distinctions between natural and artificial illumination, and ascertain when facilities for access of daylight into a building are adequate or the reverse.

It was soon realised that the most promising method of studying access of daylight into rooms was to find the relation between the illumination at some point in the room and the unrestricted illumination outside from a complete hemisphere of sky (the " daylight factor "). This quantity was of great use in the pioneering investigations of the Joint Committee of the Illuminating Engineering Society on Natural Lighting of Schools, which reported in 1914. Among other recommendations the Committee proposed that the daylight factor for schoolrooms should not be less than 0·5 per cent. The authors' experience leads them to the conclusion that workers in offices are apt to complain of insufficient light if the daylight factor falls below about 0·2 per cent.—a value which may be regarded as a useful indication of requirements in offices and factories. The daylight factor was also largely used by the Departmental Committee on Lighting in Factories and Workshops and many measurements were made on this basis.

The daylight factor should be substantially unaffected by absolute variations in daylight, though it is based on the assumption of a uniform white sky. It is determined primarily by (*a*) the area of sky visible unobstructed by neighbouring buildings, etc., (*b*) the position and dimensions of the windows, and (*c*) the nature of the decoration of walls and ceiling of the room. The measurement of the daylight factor is not a difficult process, and may be carried out by comparing the illumination on the worst lighted desk in a room either with the observed illumination from a complete hemisphere of sky, or the brightness of a portion of the sky opposite the window. Both methods have merits and the selection depends on local circumstances. Knowing the daylight factor, and having available diagrams illustrating variations of daylight throughout the day and at different times in the year, it is possible to form a fair estimate of the illumination in the room at any time.

Photometric measurements of daylight have proved of great value in connection with ancient light cases. Attention has recently been drawn in this journal to the dispute at Bradford when the Judge paid a striking tribute to the value of scientific methods, as illustrated in the data presented by Mr. P. J. Waldram. The predetermination of daylight illumination in the case of a building not yet erected is obviously a more difficult and complex problem, and the suggestions of the authors on this point deserve very careful consideration. At present the methods may appear somewhat complex to the uninitiated, but doubtless in course of time they will become simpler, and ultimately may become as familiar as the predeterminations of artificial illumination customary to-day. It is probable that many architects may prefer to solve such problems not by calculation alone, but also by the aid of experimental data. The special experimental building erected at the National Physical Laboratory affords unique facilities for work of this kind.

The subject is one where the co-operation of the lighting expert and the architect is particularly likely to be productive of good results, and we observe with pleasure that an abstract of the paper has appeared in the Journal of the Royal Society of British Architects. We hope that this will be the means of interesting many architects in the problem and enlisting their valuable efforts towards its solution.

The Cost of Daylight.

Consumers are apt to weigh very carefully the cost of installing and maintaining artificial light, sometimes not sufficiently appreciating the fact that the expense is small in comparison with the benefits secured by good illumination. On the other hand, it is a common saying that " daylight costs nothing." This is doubtless true of daylight out of doors, but in the case of indoor lighting the arrangements for securing admission of light do involve considerable expense.

This point is emphasised in a recent contribution by Messrs. M. Luckiesh and L. L. Holladay in the *Transactions of the Illuminating Engineering Society in the United States.** The various items of expense include—(*a*) the greater cost of construction of skylights and windows as compared with ceiling and walls, (*b*) the greater loss of heat from glass surfaces, which makes necessary more heating than would otherwise be required, (*c*) the cost of cleaning windows, and (*d*) the cost of construction of special light courts and wells in large buildings, and the value of the space occupied.

The authors accordingly selected typical buildings, houses, hotels, offices, art-galleries, etc., calculating the respective costs of natural and artificial lighting in each case, and allowing, for the running costs of daylight, 6 per cent. on the initial outlay in providing windows. Expenditure on artificial lighting (charges for gas or electricity, renewal of lamps and mantles, etc.) naturally varies in different buildings. But in the cases studied the expense of both forms of lighting happened to work out to about the same amount. Consumers, in considering the cost of artificial lighting, should therefore bear in mind that they do not enjoy even the light of day without paying for it.

In a large factory, with extensive glass areas, the cost of cleaning windows may be a big item. It would therefore be useful if some indication could be given to manufacturers as to the intervals at which glass should be cleaned; either as a statement of the permissible absorption of light by the glass, or a limit to the reduction of the " daylight factor," or some similar method. In the case of large buildings in congested areas valuable space may be devoted to light-wells, etc., in order to assist access of daylight. Messrs. Luckiesh and Holladay express doubt whether, in crowded city districts, such devices are worth while, and suggest that in many cases it may be more economical to rely entirely on artificial lighting. On the other hand, access of sunlight into rooms at some period of the day seems hygienically desirable.

Museums and picture galleries present special problems, and much care has been devoted to the planning of natural lighting. It is important that the colours of objects should be correctly revealed. For this purpose natural lighting has the advantage, though recent progress in " artificial daylight " appliances places artificial lighting in a more favourable position than in the past. We have also to consider the admitted prejudicial effect of sunlight in causing fading of colours of valuable objects—a matter which was recently discussed in connection with Sir Sidney Harmer's paper before the Royal Society of Arts.† On both points there is room for useful research.

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* *Trans. Illum. Eng. Soc., U.S.A.*, Feb., 1923.

† ILLUM. ENG., Nov.–Dec., 1922

Some Problems in Kinema Studio Lighting.

At one time scenes to be shown in the kinema theatre were almost invariably photographed by daylight, but during recent years artificial illumination has been very widely used. Progress in this country was illustrated in the discussion before the Illuminating Engineering Society about two years ago,* and a recent paper read by Mr. F. S. Mills in the United States affords an opportunity of comparing methods in that country.†

Speaking generally, we find many similar conclusions arrived at in both cases. We are glad, for example, to observe that the author confirms the experience in this country in regard to the desirability of screening powerful lights, particularly the searchlights now commonly used for spot-lighting, so as to avoid any possible injury to the eyes of artistes. Both arcs and mercury vapour lamps are extensively used in studios and gas-filled lamps have also special applications; in some cases it is found expedient to increase their actinic value by overrunning at about 10% above normal voltage. One interesting recent development is the use of an overhead dome enclosing arc lamps so as to obtain the desired diffusion of light.

The difference between visual and photographic effect is well illustrated by the filming of fires in the hearth, portable table lamps, etc. An ordinary fire, though highly luminous to the eye, contains too much red and orange light to photograph successfully; accordingly small arcs are concealed in the grate to accentuate the effect, miniature arcs are also used for portable table lamps with shades, and very small arcs have even been used to simulate the flame of a match used to light a cigarette, which is also too "yellow" to photograph well. The current required for certain scenes is very large; in some cases the load has attained as much as 14,000 amperes and care must be exercised to prevent overloading on special occasions, with consequent failure of the supply and interruption of the work. While the cost of lighting a scene naturally varies within wide limits, £3—£4 an hour for lighting is not unusual.

In this country much attention has been devoted to the provision of electric energy for lighting scenes. Special generating stations have in some cases been installed adjacent to the studio, and motor-trucks carrying generators have been devised to enable illumination to be provided at spots where no electric supply is available. Mr. Mills mentions some special cases of this kind in the United States where scenes had to be photographed amidst special surroundings. It is stated, for example, that in order to take a scene amidst the snow of mountainous regions it was necessary to run a 2,300v. line to the nearest power station $3\frac{1}{2}$ miles away and to shut down some of the local buildings in order to get the necessary load. Power is usually obtained from some high voltage alternating supply, reduced to a convenient pressure by the aid of transformers, and there is some danger that the period of the alternating current may synchronise with the cranking of the kinema projector, giving awkward visual effects. These have been especially evident when automatic dimming appliances are utilised. The paper gives a good impression of the large scale on which the filming of scenes is carried out in the modern kinema industry, and the variety of problems which offer scope for the skill of the illuminating engineer.

LEON GASTER.

* ILLUM. ENG., Feb., 1921.
† *Trans. Illum. Eng. Soc., U.S.A.*, Feb., 1923.

TRANSACTIONS

OF

The Illuminating Engineering Society.

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The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

WINDOW DESIGN AND THE PREDETERMINATION OF DAYLIGHT ILLUMINATION.

(Proceedings at the meeting of the Illuminating Engineering Society held at the House of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C., at 8 p.m., on Tuesday, March 27th, 1923. The presence of members of the Royal Institute of British Architects and the Surveyors' Institution was specially invited.)

A MEETING of the Society was held at the House of the Royal Society of Arts, 18, John Street, Adelphi, W.C., at 8 p.m. on Tuesday, March 27th, 1923, the Chair being taken by Mr. D. R. WILSON.

The Minutes of the last meeting having been read, the HON. SECRETARY presented the names of the following applicants for membership :—

Mr. GEO. AINSWORTH ..	Maker of Lighting Fittings, 101, Park Avenue, New York.
Mr. J. W. OGILVEY ..	Maker of Scientific Instruments, 18, Bloomsbury Square, W.C.

The names of applicants read out at the last meeting on February 20th were announced again, and these gentlemen were formally declared members of the Society.

The CHAIRMAN then called upon Messrs. P. J. WALDRAM and J. M. WALDRAM to present their paper on **"Window Design and the Predetermination of Daylight Illumination."** After the paper had been read by Mr. P. J. Waldram, the CHAIRMAN recalled that members of the Royal Institute of British Architects and the Surveyors' Institution had been specially invited to take part in the discussion.

In the ensuing discussion Mr. J. W. T. WALSH (N.P.L.), Mr. C. F. COLLINSON, F.R.I.B.A., Mr. R. LANGTON COLE, F.R.I.B.A., Mr. J. MACINTYRE (H.M. Office of Works), Mr. A. BLOK, Mr. D. R. WILSON, Mr. W. R. RAWLINGS and Mr. L. GASTER took part.

After a vote of thanks had been passed to the authors, the CHAIRMAN announced that the next meeting would be held on April 24th, when a discussion on **"The Lighting of Printing Works"** (compositors' benches, machine section, editorial and proof-reading departments, etc.) would be opened by Mr. L. GASTER.

WINDOW DESIGN AND THE MEASUREMENT AND PREDETERMINATION OF DAYLIGHT ILLUMINATION.

By P. J. WALDRAM, F.S.I., and J. M. WALDRAM, B.Sc.

(Introduction to the Discussion of the Illuminating Engineering Society, held at the House of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C., at 8 p.m., on Tuesday, March 27th, 1923, at which the presence of representatives of the Royal Institute of British Architects and the Surveyors' Institution was specially invited.)

THE main object of all investigations into natural illumination is to enable the designer to perform with confidence three operations which at present are directed mainly, if not entirely, by guesswork and rule of thumb :—

(1) So to design windows that interiors are adequately lit for their intended purposes without excessive glass area ;

(2) To determine whether any existing interior is adequately lit ;

(3) To predetermine the degree to which any proposed obstruction will affect the natural lighting of a given interior.

The problems of natural illumination are intricate, but their difficulties are apt to be unsuspected. Even to-day it is somewhat difficult to find an architect or a builder who is not convinced that he knows all that it is necessary to know about illumination by windows. It is still more difficult to find anyone who does.

Although the measurement and predetermination of natural illumination would appear to be a matter for the architect rather than for the illuminating engineer, yet the latter cannot afford to disregard it. If he is to make good its deficiencies adequately, he must have an accurate working knowledge of its nature and its weaknesses ; and as a professional man he ought to be in a position to advise his clients how best to utilise the cheapest and the best of all illuminants.

The Development of Modern Methods of Measurement.

Our knowledge of these somewhat elusive problems has only been acquired during recent years, and it is largely due to the work of this Society that we are in a better position than when it was founded.

In 1907 there was no illumination-photometer capable of measuring daylight ; its huge fluctuations were almost unrecognised, even by scientists, and the utter impossibility of estimating its varying intensity by the human eye was practically unknown. From the meagre data available certain rules for school-room windows had been deduced by continental scientists, but no co-ordinated theory on the subject had been published, and popular interest in it was small.

To-day we have Government Reports giving the results of a comprehensive series of daylight measurements taken in all classes of factories both by factory inspectors and by scientific investigators from the National Physical Laboratory, carefully collated and published with a clear and concise epitome of accepted theory.

Legal disputes with respect to obstructions to light are frequently decided upon undisputed measurements, or settled out of court ; and the unedifying spectacle is now seldom seen of eminent and patently honest professional witnesses flatly contradicting each other upon matters of opinion and observation.

This is not to say that, merely because methods of measuring daylight have been devised and have proved valuable, our knowledge is either complete or adequate for ordinary requirements. Medical science did not reach adequate finality with the invention of the clinical thermometer. Evidence that there are still gaps in our knowledge is afforded by the recent erection at the National Physical Laboratory of a building specially designed for the investigation of problems in natural lighting, illustrated in the paper read before this Society in March, 1922, by Dr. Rayner and Messrs. Walsh and Buckley.

The history of study and research in this subject prior to 1908 is almost entirely a record of the efforts of individual scientists to arrive at a proper specification of window lighting for the classrooms of public elementary schools, and for a long period it was confined to continental investigators.

A complete synopsis of continental work will be found in a short history by Dr. Kerr of investigations prior to 1913, in Vol. VII., No. 1, of THE ILLUMINATING ENGINEER.

Daylight Factor.

In 1907 study of the discrepancies between photographic exposures and the corresponding daylight values led one of the authors to the conclusion that visual impressions as to the intensity of natural illumination were most deceptive, and could be even absurdly unreliable. From this followed the logical conclusion that as any window or skylight was merely a narrow gateway through which only a very small portion of the sky could throw light into an interior, and that as the light obtainable from such a portion of the sky was, *ceteris paribus*, closely related to the visible sky area, it should be possible to express the real value of any window under any given conditions of glass, obstruction, etc., as a fraction of the daylight existing outside; and further, that such a "daylight factor" should be sensibly constant, at least under the grey and fairly uniform sky of dull days, when the effect of any obstruction of visible sky area would be more noticeable and serious.

During a search for a suitable photometer, a lucky accident revealed the fact that our Past President, Mr. A. P. Trotter, had arrived at the same conclusion some years previously. To those who know Mr. Trotter it is scarcely necessary to say that his assistance was at once placed freely at the author's disposal in connection with the design of a practical attachment to render the Trotter Photometer capable of dealing with the huge intensities of daylight; in the formulation of an outline theory; in the consideration of experimental results, and in obtaining facilities for measuring typical public buildings. He has disclaimed, in favour of the author, all credit for the practical development of what must, even if only in point of date, be regarded as his theory, but he greatly assisted that development.

After the first daylight attachment, built up of blackened cardboard tubes, had proved beyond reasonable doubt that measured daylight ratios remained sensibly constant over large ranges, progress was fairly rapid. Daylight factors in terms of zenith sky brightness, were measured in public and private buildings in considerable numbers; continuous records of daylight variations in London were kept and the results published from time to time. The new method was promptly adopted by the Home Office for use in factory inspection, and the results of records made by H.M. Inspectors were published annually in the official reports. It was applied to the determination of ancient light disputes with some success. The invention of the Holophane Lumeter Photometer by Messrs. Dow and McKinney, and of the Luxmeter by Mr. Edgecumbe, all members of this Society, reduced considerably the labour of measurement, and both instruments were adopted and used by the Home Office.

Home Office Report on Factory Lighting.

The Departmental Committee set up by the Home Office early in 1913 to investigate the lighting of factories and workshops, disclosed the need for authoritative data. This was duly compiled by the National Physical Laboratory, who reported that the method of measuring by ratios was not only the most reliable, but the only reliable method applicable to daylight illumination.

The demand for copies of the First Report of this Committee exceeded the supply, and it is now out of print. It is to be hoped that the Committee will continue this valuable work. Meanwhile it was gratifying to learn from Dr. Rayner's paper, already referred to, that the investigation of problems in daylight illumination is to proceed at Teddington at the instance of H.M. Office of Works.

The Use of Models in Research.

In 1907 Dr. Ruzicka suggested in an article in THE ILLUMINATING ENGINEER that daylight problems might be studied

in scale models. One of the authors carried out some experiments to ascertain whether the "daylight factors" of typical points in a room of which the windows were partially obstructed by buildings opposite, the obstructing wall surfaces having a measurable coefficient of reflection, would accurately be reproduced in a scale model of the room and window opposed to scale model obstruction coloured to give similar coefficients of reflection.

From these experiments he formed the opinion that model tests were reliable if suitable precautions were taken, and advocated their adoption to this Society in 1908. In 1913 he secured the invaluable assistance of Prof. Clinton, and carried out with him at University College a somewhat drastic and exhaustive test of the accuracy of model tests, the results of which were duly communicated to this Society (*vide* ILLUMINATING ENGINEER, Vol. VII., No. 1). Further reference to Dr. Rayner's paper shows that the accuracy of scale models has been completely accepted by the National Physical Laboratory.

In 1907 the author further suggested that much time and trouble could be saved by the use of an artificially uniform sky mounted on a light hemispherical framework to permit of the separate investigation of the relative values of different sectors or angular elements of sky, but apparently this has not yet been adopted at Teddington.

The new daylight building which is described and illustrated in Dr. Rayner's paper has open sides and a glass roof, and seems to be designed to receive scale model rooms, sufficiently large to accommodate an observer and his instruments and lit from the sky.

The accuracy of this method for research work as compared with that in which models are measured from the outside through apertures would appear to be open to question.

Committee on School Lighting.

During 1912 and 1913 a Committee appointed by this Society, including school medical officers and teachers, undertook the investigation of the lighting conditions of schools. The recommendations contained in their Report on Artificial Lighting were strongly recommended for adoption by the Chief Medical Officer of the Board of Education in his Annual Report in 1913, and the Committee's Second Report, dealing with the daylight lighting, was published shortly before the war.

Fortunately the publication of the Report was sufficient early to secure comparison of its recommendations with those of continental scientists up to that time, and it was not without significance that the main recommendation of the Report to the effect that the daylight factor for the worst desk should be one per cent. of the light on an unobstructed window-sill proved to be precisely identical with the recommendation of Dr. Weber, as the result of many years of patient work by himself and Dr. Cohn, upon lines of investigation totally different to those adopted by the Committee.

It will be seen that the foregoing record of progress, important though it be, is confined to the measurement of daylight illumination and to definition of its adequacy for different purposes. In spite of large and unsuspected fluctuations, it is now possible to measure daylight and to value it for comparison with recorded averages found sufficient for similar or different purposes.

But the rules for obtaining any given daylight factor under any given circumstances have still to be written. The photometer will tell us what we receive under any given conditions; but it will not tell us how we may obtain the same illumination under different circumstances, nor what we shall obtain if the circumstances be changed. We can now measure, but we cannot yet predetermine daylight. In the following paper, methods are suggested by which this may be accomplished.

The Principles of Daylight Measurement.

The problems relating to illumination derived from the sky have but little in common with those dealing with illumination from artificial sources. In the case of the latter the source of light remains steady; it may be measured, if necessary, on the photometric bench, and it is possible not only accurately to determine its candlepower in all directions, but also to be reasonably

sure of those candlepowers remaining at the same value when the source is installed in a room. Similarly, a reading of illumination taken in a room under artificial lighting conditions would naturally be expected to remain constant, and its predetermination presents no very serious difficulty. Moreover, there is no great difference between the measured value of the illumination and the impression of adequacy or the reverse which it conveys to the eye.

But daylight illumination is far less simple. The source which illuminates interiors is the sky visible through some aperature, and the brightness of this source is by no means constant. It varies not only from minute to minute, from hour to hour, and from month to month, but it can vary also at any given time over even a small area of sky; the daily and seasonal variations being not merely of the order of ten or twenty per cent., but often as much as five or six hundred per cent., whilst the variations in brightness in different portions of the sky can be as much as 100 per cent.

But the fact that a sky of uniform brightness seldom occurs for more than short periods does not necessarily mean that a serious or even any error is introduced, provided that the measurements are so conducted as to eliminate the error.

It is, however, evident that an isolated reading of the indoor illumination without reference to the outside conditions can by itself have no value whatever, for if taken five minutes later it may equally well be twice or half as great. Moreover, these differences, enormous though they are, pass quite undetected by our eyes, which, without our being aware of the fact, are continually adjusting themselves to the varying intensities of illumination to which they are exposed. Herein lies another and most important difference between artificial and natural illumination, for the ocular mechanism which operates so perfectly under natural light fails almost entirely to cut off excess of artificial light; and we are in consequence accustomed to misjudge daylight illumination to an enormous extent; thinking, not unnaturally, that if our eyes tell us at once when artificial illumination varies, they would also detect variations of a similar magnitude in daylight illumination—and where we perceive no difference we suspect none.

Hence, although artificial illumination may be judged by the eye with fair accuracy, the opinions of any two observers who attempt to judge daylight illumination by the unaided eye at different times are likely to differ greatly; even ridiculously.

The light by which we perceive objects in reading and writing, in all ordinary indoor work, and in the vast majority of industrial operations, is that which is reflected back from those objects in a more or less vertical direction. The more important problems of the daylight lighting of interiors are consequently those which affect the value of the illumination which falls vertically on to a horizontal plane at table height. The following considerations are therefore directed exclusively in the first instance to such vertical illumination. Special cases such as the lighting of library bookshelves, stores, picture galleries, packing case labels, cloth perches, etc., in which horizontal illumination is the more important, can, it is suggested, be dealt with by a simple modification of these methods to which vertical illumination is amenable.

Although the principle of expressing the natural illumination of interiors as a fixed proportion of the light from the unobstructed sky outside has been unanimously accepted and widely used, it cannot be said that the methods by which it has been applied to practical problems are satisfactory, or even that the essentials of the principle have been properly grasped.

It is therefore necessary briefly to examine and define those principles as a preliminary to describing a method of measuring which is more logically in accordance with them than that which is described in Government reports. This method has been found by the authors to be also simpler and less conducive to errors. It furthermore offers reasonable prospect of very greatly simplifying the means of collecting sufficient experimental data to determine those troublesome questions of diffusely reflected light which still bar the way to any complete and logical theory, applicable to all ordinary problems.

Daylight illumination, like every other problem in illuminating engineering, reduces to the task of expressing in figures the opinions of average persons; of establishing standards above which the conditions may be taken as reasonable, and below which they are unsatisfactory; and of defining what is necessary for any given purpose.

Daylight is here at a further disadvantage as compared with artificial light. The adequacy or inadequacy of the latter can readily be judged with fair accuracy by any person with normal vision; but a reliable estimate of the natural illumination of a room can only be made, without instruments, by living and working in it over a considerable range of weather. Average persons, unaware of the eccentricities of their most accurate sense, are almost certain to be misled by any casual inspection of daylight conditions.

But even when the observer appreciates that the criterion of adequacy or otherwise is not the light which happens to be in a room at any moment, but the light which *ought* to be there in view of the sky brightness obtaining at the moment, yet his judgment is still liable to be upset by unconscious prejudice.

A room which is in reality badly lit may look quite bright on a sunny day or when bright clouds are about, especially if the walls be of a cheerful tint. On the other hand, a room which is really well lit may seem quite gloomy when it is receiving its light from a cloudless blue sky, which suggests so much light and which produces so little; more especially if the walls are of drab and depressing tints, such as those of the Law Courts.

But the photometer is quite impersonal, as is the clinical thermometer, and it is equally free from prejudice. Intelligently used, it is capable of giving us by a few readings information which could otherwise only be acquired by long residence.

As in all inquiries, scientific or otherwise, it is necessary clearly to define the issues sought, and to keep the mind constantly focused on them, continually testing the value and relevance of all evidence submitted.

In the investigation of daylight problems this precaution is of especial importance, on account of the fatal facility with which irrelevancies, preconceived ideas, and deceptive similarities tend to throw the real issues far out of focus or to give a false value to evidence.

We are seeking to establish methods which shall be true criteria of the considered opinion of ordinary persons, as distinct from their casual impressions. What then are the factors upon which such opinions are built up during a fairly long period of user with regard to the natural lighting of an ordinary room?

The principal considerations are:—

(1) Lighting up times.

(2) The adequacy of illumination between lighting up times under normal conditions of weather, as indicated by freedom from eyestrain.

No method of measurement can therefore be correct unless its results give a true measure of these criteria.

Lighting-up Times.

It will be obvious that if we possess reliable data of daily and seasonal variations in the outside light, such as is indicated in Figs. 1 and 2,* and if we can measure the daylight factor at any given point in an interior, then we know what proportion of the outside light is available at that point, and the calculation of lighting-up times becomes extremely simple. For instance, if the factor for a given point in a room were 0·5 per cent., and the required illumination were 1 foot-candle, then this illumination will only be received over those periods during which the outside illumination is at or over 200 foot-candles.

If, therefore, we can so measure the daylight factor that it is a true proportion of the recorded outside light (and this proviso is of no small importance) then the adequacy or inadequacy of natural lighting, in so far as it can be judged by average lighting-up times, is capable of exact determination by means of daylight factors.

Adequacy of Illumination between Lighting-up Times.

At first sight it would appear that if, say, 1 foot-candle or any other given

* Reproduced from "The Elementary Principles of Lighting and Photometry," by J. W. T. Walsh (Methuen), by kind permission of the author and publishers.

intensity of illumination were found sufficient for a given operation, and if the periods over which a given point in an interior will receive that illumination or more are known, then the adequacy of illumination between lighting-up times would appear to be assured, but this is not so.

In the presence of adequate daylight the eye often seems to lose all sense of reasonable proportion and to behave almost like a spoilt child, absolutely refusing to be satisfied with that degree of illumination with which it is cheerfully content at the lean periods of dawn and dusk. The reason for this is that the eye is sensitive to sources of bright light which may be outside its line of direct vision. A person needing 1 foot-candle and working in a position lit by an inadequately small patch of relatively bright sky, or at the relatively dark back of a deep room, may have 4 or 6 foot-candles to work by. But if his eyes are conscious of the piece of bright sky or of brighter parts of the

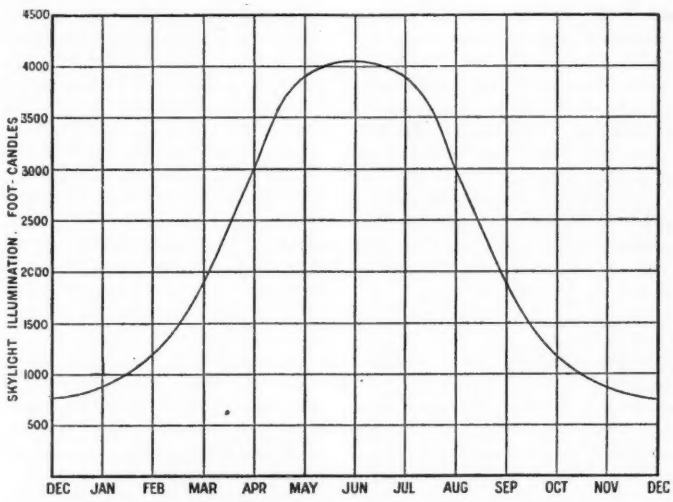

FIG. 1.—Yearly variation of skylight at noon (Teddington).

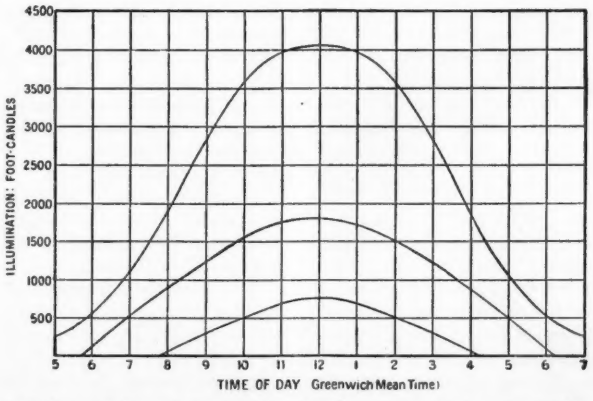

FIG. 2.—Daily variation of illumination at Midsummer, Equinox, and Midwinter.

room he may find the light less adequate than 1 foot-candle on a dull day. This is not only because he feels that he is getting less than he ought to have, but also because the iris diaphragm of the eye is partially closed by the consciousness of the brighter patches, even though those bright patches may lie outside the immediate line of direct vision. The necessity for obscuring window panes in front of lens makers, and the difficulty which school children find in reading under the shadow of an open playshed roof when facing the open sky are well-known examples of the severity with which adequate daylight is discounted by the effect on the eye of strong contrasts. or of what is known as a high diversity factor.

Very fortunately, however, the same causes which reduce daylight factors, viz., inadequate visible sky area—whether caused by small or low windows or by obstructions and/or by dirty glass and dark walls and ceilings—also tend to increase the diversity factor. Inadequate light from windows in a room always involves sharp and hard contrasts, *i.e.*, a high diversity factor. With adequate light these contrasts disappear. The typical cellar, with a window about a foot square, is an example of low daylight factor and high diversity factor, whilst in the typical elementary classroom where the worst desk receives 1 per cent. of the light falling on an unobstructed window-sill, the diversity factor is imperceptible.

Daylight factors are, therefore, not only correct measure of lighting-up times, but they are also a very fair and possibly a quite accurate criterion of diversity factor, which is at least the most important of those visual prejudices which affect the judgment of adequacy between lighting-up times.

"*Grumble Point.*"

After some years of experience in measuring and valuing daylight illumination in a variety of cases, which have included the most diverse conditions, the authors have found no occasion to vary the opinion formed from consideration of the results obtained in the first batch of public and private buildings measured in 1912. This was that for ordinary purposes, comparable with clerical work, the natural illumination at which average reasonable persons would consistently grumble was that which represented 1/250 (0·4 per cent.) of the outside illumination which would fall on a window-sill from an unobstructed quarter-sphere of sky, of the same brightness as that of the patch of sky which illuminated the position under consideration. This grumble point is, of course, the same as 1/500 or 0·2 per cent. of the light which would fall from an unobstructed hemisphere of uniform sky on to a flat roof.

Although it has no official status and has not been, as far as the authors are aware, investigated by the N.P.L., it has survived the drastic test of many closely contested ancient light cases, and is more or less confirmed by the data of existing conditions in factories contained in the Home Office Report.

A minimum of 1 per cent. on the worst desk of public elementary schoolrooms was recommended in 1914 after searching inquiry by the Committee of this Society. As already mentioned, precisely the same figure for schools was arrived at quite independently on the Continent.

As this school minimum is $2\frac{1}{2}$ times the suggested minimum for ordinary clerical work, the latter would appear to be not unreasonable.

As regards the lighting-up times, a working position which requires a minimum of one foot-candle and enjoys a daylight ratio of 0·4 per cent. would, according to the published N.P.L. data, require artificial light in average weather from two hours before sunset until two hours after sunrise, *i.e.*, it would be necessary to light up at six p.m. at midsummer and at two p.m. at midwinter.

The school minimum of 1 per cent. would have one foot-candle at the worst desk for two hours per day more than this in the morning and a further two hours in the afternoon.

Grumble points for different special purposes in trade and manufacture can be estimated by reference to the data in the Home Office Report.

But correct measurement of daylight factors is essential, and this may now conveniently be considered.

An important point affecting methods of measurement is that we are accustomed to judge the conditions of natural illumination at any point by the brightness

of the particular patch of sky which is visible from the point in question, and that our judgment of natural lighting conditions is unaffected by the brightness of any part of the sky which is not visible from that point. In this respect the method of measurement suggested by the authors will be found to be in agreement with the methods instinctively adopted by users of the room in forming an estimate of its natural lighting.

Definition of Daylight Factor.

It is submitted that the true definition of the daylight factor at any point in an interior should be :—

"The ratio of the illumination at the point to the illumination obtainable from a complete unobstructed hemisphere (or quartersphere) of sky, *of the same brightness as that of the portion of sky which can throw light on the point under consideration.*"

The necessity for observing the condition printed in italics has frequently been overlooked; inaccurate and illogical methods of measuring have been introduced, and the accuracy of daylight factors has in consequence been questioned.

Methods of measuring Daylight Factor—Zenith Method.

When the system of measuring and expressing daylight was first introduced by one of the authors, there were no illumination-photometers capable of measuring sky brightness, and he was forced to devise a fitting whereby the Trotter Photometer could measure the light from a small and defined area of sky. This was for convenience taken at the zenith, which is free from the sun and from the brilliant illumination of clouds near the sun. By measuring always at times when no sun could enter the room, and preferably on a grey day, the zenith method involved very little error.

Complete Hemisphere Method.

When, however, the Lumeter and Luxmeter Photometers with their reducing screens became available, the National Physical Laboratory, when measuring a large number of factories for the Home Office Committee, evolved a new definition of daylight factor as the proportion between the illumination at a point in an interior and that which it would be if the walls, ceilings and all obstructions were removed; the interior reading on a white card being balanced against a simultaneous reading on a similar white card taken on an unobstructed roof.

This method might be considered to be more theoretically attractive, but it requires for accuracy :—

(1) An absolutely uniform sky;

(2) An infinitely small observer on the roof.

These conditions being both unattainable, the N.P.L. method necessarily involves the two errors: (A) due to the head and shoulders of the observer on the roof, blocking out a large and variable proportion of the theoretically complete sky; and (B) that due to the interior light being balanced against sky aspects which can never illuminate it. For example, a north-east window is unaffected by a south-west sky, and in so far as a north-east sky differs from a south-west sky this method must be in error. If the interior illumination is to be balanced against that from a hemisphere of sky, it must be one of the same brightness as that of the piece of sky actually lighting the point in the interior. The illumination from such a uniform sky can of course be deduced from measurement of the illumination from any given portion of sky, as was done in the author's original zenith method.

Sill Light Method.

The Committee of this Society which investigated the Daylight Lighting of Schools eliminated the main error of the N.P.L. method by balancing against the light falling on an unobstructed card on a window-sill having the same aspect as that of the particular window under consideration. The authors have made considerable use of this compromise, and, given reasonable weather, very few precautions are required to secure reliable results; but, although involving less risk of error than the N.P.L. method, it is by no means perfect.

New "Sky Brightness" Method.

The main source of inaccuracy which is common both to the roof and to the sill method is that the card used for outside

measurements is illuminated by a complete hemisphere or quartersphere of sky, whereas that used for the interior is lit by a very small patch of it. The illumination on the outside card is therefore an average, which takes into account the variations in brightness of parts of the sky which cannot be seen from the card inside the room and with which it is not concerned. Suppose, for example, that there is a small bright cloud or patch of twice the brightness of the rest of the sky (which is by no means uncommon), which is moving across the sky at a constant elevation. It will make no difference at all to the outside card as it moves, but when it comes opposite to the window so as to illuminate the interior at the point under consideration, the reading there will be increased, and may even be doubled if the patch is sufficiently large.

A more satisfactory method, which enables the inside and outside readings to be taken within a few seconds of each other by one observer, without involving any of the above objections, and which, moreover, gives results more in accordance with average considered opinion, dispenses with the outside card altogether. A reading is taken directly on the sky visible from the point in question with an illumination photometer of the internal screen type, and the illumination which an outside card would have received, had all the sky been of that brightness, is calculated. This measurement can usually be made without the observer changing his position, and moreover saves the expense of a second observer and instrument and, to a considerable extent, the delay of waiting for particularly good weather conditions. All such measurements are of course impossible when the sky is very patchy or when the sun is shining into the room, but this method permits of measurements being taken under conditions which would render them extremely difficult and probably inaccurate by any of the other methods.

It will be shown (see Appendix II.) that the brightness of a perfectly white matt card is equal to the brightness of the sky which illuminates it, if there is no obstruction (as for the roof method), and to half that value when it is exposed to half the sky (as in the sill method). It is of course necessary to make due allowance for the fact that the card used for interior readings is not perfect. The outside "card," being imaginary, is theoretically perfect, but that used for interior readings, being a real card, does not reflect all the light which falls on it, and it is therefore necessary to divide the factor obtained by this method by the reflection ratio of the card. In previous methods, since an actual card was used in both cases, this error cancelled out and was not considered.

If the sky must be observed through the window glass, the absorption of this should be measured and allowed for, since absorption by the glass is the fault of the window and should be charged against it. This correction acts in the opposite direction to that for absorption by the card.

Even with these precautions it is necessary to take several readings at each point and to average the results, if accurate results are required. In taking a sky reading, the instrument should be adjusted till it is as much out of balance in one direction at the lighter parts of the sky as it is out in the other direction at the darker parts. For reasons which will appear later, most attention should be paid to the region near 45° elevation, when taking interior readings on a horizontal surface. Not less than three separate determinations should be taken for each point and the results averaged. Under certain conditions it is easy to obtain a false result for a factor from a single reading.

Direct and Diffused Light Factor.

So far the "factor" considered has been that obtained from that total light incident on the interior card. This light may be considered as being made up of two portions, the greater part coming directly from the sky, and the remainder coming by reflection from the walls, ceiling and furniture of the room. It is sometimes necessary to know how much of this light is direct and how much is reflected or "diffused" light, and for this purpose the authors constructed the piece of apparatus shown in Figs. 3 and 4, which proved entirely satisfactory.

A lath about 3 ft. in length carries two sliding blocks, of which one, at the end of the lath, has a travel of half its own length, and the other of which can slide the whole length of the lath. The first

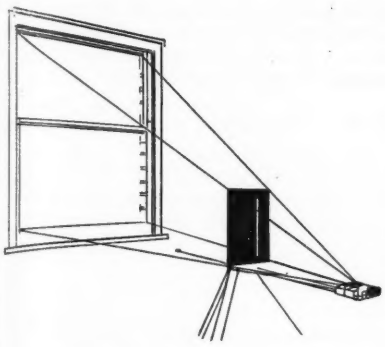

FIG. 3.—Apparatus for measuring diffused light.

block carries a small horizontal white card, so arranged that by sliding the block either the centre of the card or the end of the block (which carries a small peep-sight just above the level of the card), can be brought over the end of the lath. The other block carries in a clip a vertical black card.

In use, the lath is fixed in a horizontal position, pointing towards the window, on a tripod or otherwise. The end block is moved up so that the peep-sight is over the end of the lath and, looking through the sight, the block bearing the vertical black card is moved until the card appears exactly to cover the window opening. The white card is now pulled back so that its centre coincides with the position previously occupied by the peep-sight. The centre of the card is now lit only by light from the walls and ceiling, and a reading taken on it thus gives the intensity of the diffused light at that point. By removing the black card the total light incident at the point may be read, and a reading taken on the sky before and after the other two will enable the factors to be calculated, so that the total factor may now be divided into its two constituents, the diffused light factor and the direct light factor. Reference to the value of these factors will be made later.

Calculation and Predetermination of Daylight Factor.

The above methods will only tell us what are the lighting conditions which actually obtain in any given case. With them it is impossible other than by the use of models, to measure with a photometer the light which was obtained before another building was erected in front of a window, or—unless a full-size screen be erected—the light which will be obtained when it is eventually built, or to determine by actual experiment what will be the conditions in a proposed building. These are obviously matters for calculation, and it is proposed now to show how the direct light factor can be calculated for any given case, whether actually built or not, under any conditions of obstruction whatever.

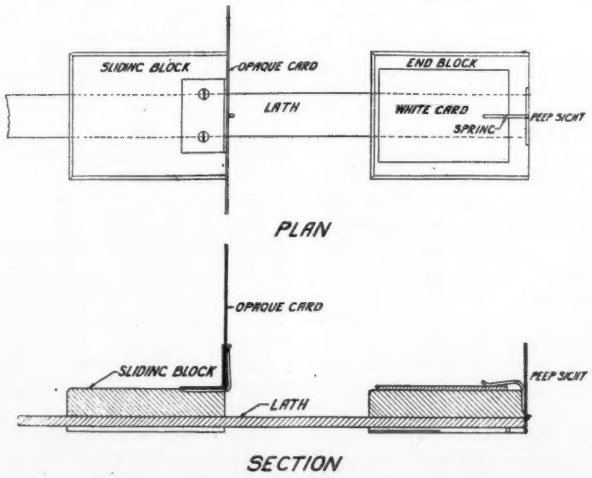

FIG. 4.—Apparatus for measuring diffused light.

In all calculations of daylight, the assumption of uniform sky brightness is absolutely necessary. The logical correctness of this has already been shown. The lighting-up time is determined by the brightness of the sky which lights any point; it is not affected by the brightness of the rest of the sky. The grumble point of reasonable people is determined by the brightness of the sky which they can see through a window. Neither is affected by the fact that a bright sunset or sunrise may be taking place on the other side of the house.

The actual vertical illumination at a given point in an interior due to a small patch of sky is dependent on three factors, viz.: (i.) the average brightness of the patch; (ii.) the area of the patch; and (iii.) its average angular elevation.

The first quantity is expressed in foot-candles, since most illumination photometers are calibrated in these units. A surface is spoken of as having a brightness of E foot-candles when its brightness is equal to that of a perfectly matt white surface receiving E foot-candles normally. It can easily be shown that, where the cosine law of emission holds, the normal candlepower per square foot of surface is $\frac{E}{\pi}$.

The area of a piece of sky must be expressed in some form of solid angle; either in square degrees, a square degree being the solid angle subtended by a small square of such size and at such distance from the point of observation that each side subtends one degree of arc or else in the orthodox unit, sometimes called the "steradian," which is measured by projecting the piece of sky on to the surface of a sphere by radial lines, and by dividing the projected area by the square of the radius of the sphere.

1 steradian = 3,283 square degrees.

The angular elevation of the patch of sky naturally comes in, for it is obvious that light which is incident at a low angle of elevation on a horizontal surface will be of less effect in illuminating it than light which falls more nearly normally, and by Lambert's law the illumination falls off as the cosine of the angle of incidence, or, in this work, as the sine of the angle of elevation.

Weber and Cohn employed a system of measurement which takes into account both the area and the angular elevation of each element of sky, the result being expressed in "reduced square degrees."

Pleier's Formula.

For points in a room situated far from a window, a formula was worked out by Pleier giving approximately the reduced square degrees of sky visible from any point in a room. The method of obtaining the formula is given in Appendix II., and the result is:—

$$\text{Reduced square degrees} = \frac{3{,}283\ ahmo}{(m^2+n^2+o^2)^2}$$

(See Fig. 17.)

This formula is approximate only, for as will be seen in Appendix II., the sine of the mean angle of elevation is taken instead of the means of the sines of the angles of elevation of each element. The results are for this reason too high, especially for points which are close to the window.

If the result found above be divided by the number of reduced square degrees in a quartersphere of sky, the formula gives an approximation to the direct daylight factor for the point under consideration, neglecting the absorption of the glass

$$F = \frac{0{\cdot}636\ ahmo}{(m^2+o^2+n^2)^2} \text{ approximately.}$$

It is, however, somewhat difficult to set out such measurements as a, h and o in practice (see Fig. 17), and, in the opinion of the authors, it is more satisfactory to deal entirely with angular co-ordinates, as these may more readily be obtained from plans and sections.

Formulæ giving Direct Daylight Factor.

They therefore devised the following formula:—

Let F = the ratio of the direct sky illumination, measured vertically, at a point in an interior, to the light on a window-sill receiving all the light falling from a quartersphere of sky of uniform brightness.

Let ϕ be the horizontal angle of visible sky subtended at the point, measured in radians.

Let θ_1 be the vertical angle of elevation, measured in a plane normal to the window, of the top of any obstruction (supposed

for this purpose to be of uniform height and indefinite extent, parallel to the plane of the window).

Let θ_2 be the similar angle of elevation of the top of the window glass, *i.e.*, of the "top" of the visible sky.

Then $F=\frac{\phi}{2\pi}(cos2\theta_1-cos2\theta_2)$.

The mathematical proof of this will be found in Appendix II.

Diagram for the Predetermination of Daylight Factors.

There is one objection which applies to any formula for direct light. The obstruction is invariably assumed to be caused by a horizontal unbroken building, parallel to the window, stretching right across the field of view—an assumption which, although very convenient for the construction of formulæ, is very inconvenient to their users. Obstructing buildings have no regard for the conditions which are easily calculated, and appear with gables, projections, changes of level, chimneys, etc., making the labour of dealing with the problem by treating each small piece of sky separately very considerable. Moreover, no formula takes into account the effect of the bars of the window, which, owing to their small distance from the point of observation, cause a surprisingly large reduction in the daylight factor.

The authors have, therefore, devised the chart or measuring diagram shown in Fig. 5, which greatly simplifies the use of the method. The window and obstructions are plotted by means of their angular co-ordinates, the scales being so proportioned that the areas of patches of sky shown on the diagram are proportional to their lighting values. The area of the whole diagram being proportional to the lighting value of a quartersphere of sky, by dividing the area of sky shown on the diagram by the area of the diagram the direct daylight factor can at once be obtained.

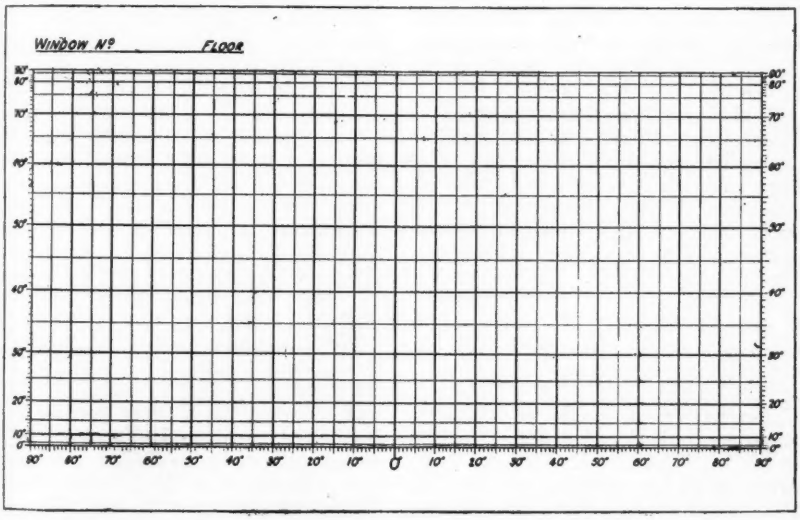

FIG. 5.—Measuring diagram for direct light factor; illumination measured vertically on a horizontal plane.

The method of constructing the diagram will be found in Appendix II.

It will be seen that in the above diagram the vertical scale contracts both towards the top and towards the bottom, while the horizontal scale is even. The latter scale raises the question of the value of light which enters a window laterally, and indicates that such light is given the same value in the diagram as light which enters from directly in front. It is sometimes said that light which enters laterally is of little use. When speaking of the room

as a whole, that is to some extent true, since lateral light cannot enter very far into the interior. But the diagram is concerned not with the room as a whole, but of one single point in that room, and with the vertical illumination at that point. It must be obvious that in dealing with vertical illumination the horizontal direction of the incident light is quite immaterial, provided that the vertical elevation is compensated in accordance with Lambert's law, as is done in the diagram by the construction of the vertical scales. If the point does receive lateral light, it is just as useful as that which comes from directly in front.

The contraction of the vertical scale towards the bottom is accounted for by Lambert's law, giving smaller values to the light from lower angles. But the scale also contracts towards the top of the diagram, which seems at first sight to contradict the well-known fact that high angle light is of great value in producing vertical illumination. The explanation of this apparent contradiction will be clear from reference to Fig. 18, Appendix II. Let us consider a horizontal zone of sky, subtending a vertical angle of 1°, and note its effect at different elevations. Near the horizon, the zone is nearly a great circle of the sphere and its area is large. Unfortunately, although we obtain a large area of sky for our "degree's worth," it is of very little use to us by reason of its low elevation, as shown by the bottom contraction of the diagram scale. As we rise higher up the sky, however, the zone becomes a small circle of the sphere, its area decreasing according to the cosine of the angle of elevation, and at the zenith, although it is most useful in illuminating a horizontal surface, we obtain no sky at all for our "degree's worth." Thus, at the horizon the sky is fairly cheap, but of little use; as we approach the zenith the value of the sky increases, but the price grows prohibitive, for there is very little zenith sky. Thus the part of the sky thus measured in degrees which is most useful for lighting a horizontal surface is that in the neighbourhood of 45° elevation, where the vertical scale of the diagram is most open.

In this connection it should be remembered that angles are to be measured in a definite way—the horizontal angles are to be measured in a horizontal plane, as with theodolite, whether referring to an elevated object or to one on the horizon. A little consideration will show that the horizontal angular *measure* of, say, a bright patch of sky is not constant, but increases with its elevation; but the horizontal measure of such an object as a vertical chimney is always the same.

In setting out the building it is necessary to have plans and sections of the buildings under consideration of their surroundings and of the proposed additions or alterations. These will, naturally, be available, since if all the buildings were *in situ* there would be no need for diagrams at all, the factors could be observed with a photometer.

The central vertical angles and the horizontal angles may be scaled directly from the drawings, but oblique vertical angles must be obtained from their tangents or by some similar method, since the horizontal distances are not given on the sections. It is possible to obtain the angles from a special perspective drawing.

For the rapid plotting of diagrams for existing buildings, where plans are not available, the following method was adopted with very satisfactory results. A quarter-plate camera was used to give an image of the window and the obstructions on the focusing screen, the latter being so divided by pencil lines as to give the vertical and horizontal angular co-ordinates of the objects in the field of view. It is necessary to use a fixed focus to the camera, otherwise the scales will be incorrect. In use, the image was sketched from the focusing screen on to a piece of similarly divided graph paper and the diagram plotted from the sketch. By this means a complete diagram, showing far greater detail than could be obtained from plans and sections, can be drawn and measured in about twenty minutes.

It would doubtless be feasible to use the camera for obtaining an actual photograph of the buildings, and, by means of a suitable mask, to incorporate with the prints the lines giving the vertical and horizontal angles. Where

a large number of diagrams have to be drawn this method would save a very great deal of tedious work. A method has also been suggested by which the measuring diagram itself may be obtained photographically, although no attempt has been made up to the present to put it into practice. The expense involved in the use of such a method would only be justified where a very large number of diagrams have to be prepared in a short time.

When the whole window cannot be included in the field of view of the camera in one setting, it must be turned *with the lens as a centre* through 5° or 10° as required, but no horizontal angles should be taken when the camera is inclined to the horizontal.

If the camera has a rising front, it should be calibrated with the lens as high as possible, as by this means it may be made to include more of the window in one setting.

For setting out sun or direct light diagrams from drawings the authors have found that a very great saving of time and labour can be effected by setting up a perspective view of the outlines of the buildings, and using this view in conjunction with a suitable mask, divided in such a way as to give the angular co-ordinates of the objects seen in the view. Fig. 6 shows an ordinary perspective view of the buildings which are seen in Figs. 7 and 8 as projected on to a hemispherical sky and as in a direct light diagram respectively.

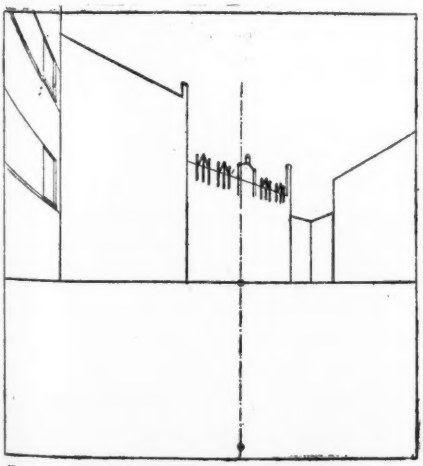

Fig. 6.—Typical perspective view of obstructing buildings.

Diffused Light.

The light received directly from the sky through a window falls off very rapidly indeed as the distance from the window increases, for the amount of visible sky decreases very rapidly (Fig. 9). In many rooms no sky at all is visible at table height well before the back of the room is reached. But all the light which enters a room falls on to some object, such as a wall, the floor, the ceiling, or the furniture, and part of it is reflected from them in all directions, only to fall on other objects and to suffer reflection again. Each reflection absorbs a part of the light, but the general effect is that a fraction of the light entering a room through the window is spread more or less evenly over the room, as in the sphere or cube photometer. Such experiment as the authors have been able to make indicates that the proportion of the total daylight factor which is contributed by such diffusely reflected light is fairly constant over the extent of an ordinary room of ordinary proportions. Its value is not great; in a very shallow room, with a large window, and light walls and ceiling, it may approach 1 per cent., but it would appear that in all cases of serious sky obstruction by opposing buildings or of low daylight factors from other causes the factor for diffused light alone will be below the grumble point of 0·4 per cent. sill ratio.

The contribution to total daylight factors which is made by diffused reflection or, as it is generally called, "diffused light," is not usually great enough seriously to affect the total natural illumination found in the room, except at situations near to the back wall. Its most valuable function is to tone down strong contrasts, and to enhance the cheerfulness of a room, by assisting the illumination of such parts or surfaces as are not directly lit by the sky. A dark wall or corner, although it may be well away from the working plane, will give a gloomy impression, and may even cause eyestrain in some cases by "successive glare."

Everything, therefore, which aids diffuse reflection is of value; wall coverings which are light in tone and are kept

clean, and ceilings which are kept white, will often make all the difference between cheerfulness and gloom.

Light, as such, is invisible unless reflected into our eyes, and the presence of a wall or other surface which cannot reflect light because of its high absorption has just the same effect upon persons using the room as a surface which could reflect light but which is dark because there is little to reflect. Dark walls give an impression of inadequate lighting which it is difficult to eradicate.

In badly obstructed rooms the diffused light becomes more valuable, since comparatively large spaces are entirely dependent on it for their lighting.

It should be noted that light entering a window laterally can materially contribute to the diffused light factor. Only when the direction is so oblique that it is unable to enter the window at all does it become of any less value to diffuse reflection than that which enters normally. Certainly it does not penetrate so far into the room, but to those portions of the

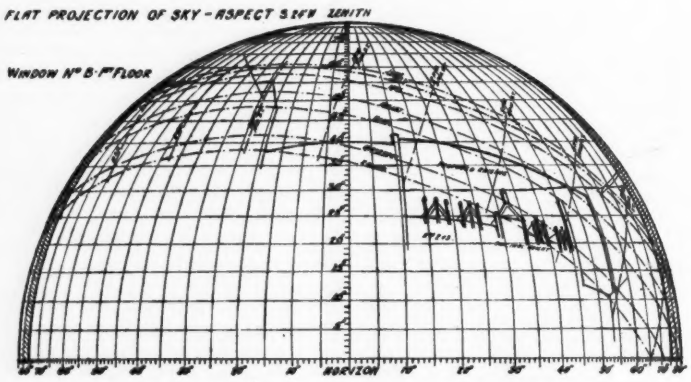

FIG. 7.—Typical diagram showing loss of sun due to obstructions.

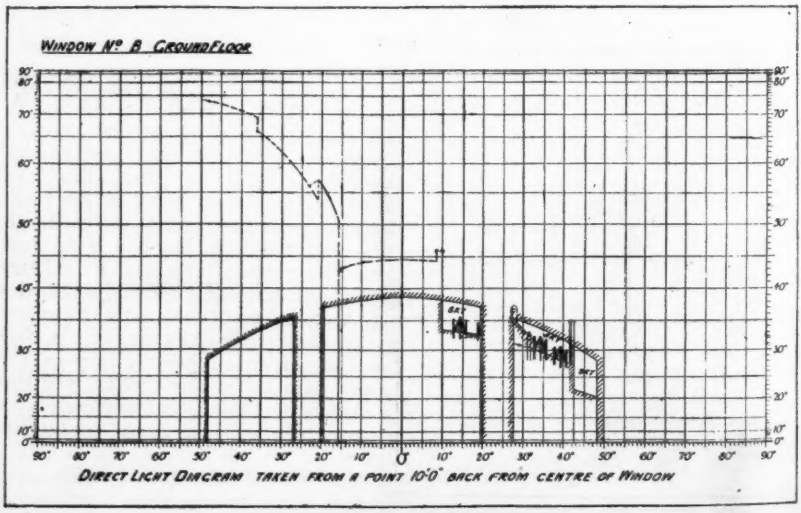

FIG. 8.—Typical direct light diagram.

working plane on which it falls directly, and for the purpose of creating diffused light, it is as valuable as normal light.

From this it follows that a room with bad lateral obstructions is affected by an obstruction in front far more than one which is otherwise unobstructed; and that rooms with bad front obstruction may be seriously affected by an obstruction well to one side which would otherwise be immaterial.

in the window through which light can enter over the maximum number of directions, would give a measure of the diffused light, and taken in conjunction with a suitable utilisation factor might give the actual value of the diffused light (see Fig. 23). Such a diagram should, in any case, give the reduction in diffused light due to any increase of obstruction, even if the utilisation factor were unknown.

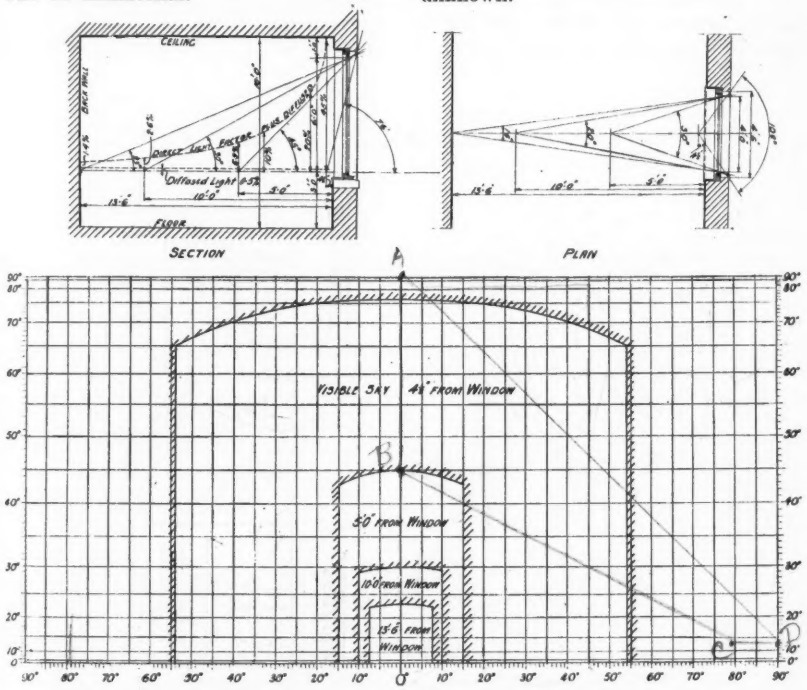

FIG. 9.—Loss of visible sky and typical decrease of light with increasing distance from window.

Predetermination of Diffused Light.

The subject of the predetermination of diffused light is rather different from that of the predetermination of direct light. It depends on two factors—(i.) the utilisation factor of the room, and (ii.) the flux of light entering the windows. From the nature of the problem, it would appear that the direction of the light will be of no consequence, and hence it seems likely that a diagram constructed similarly to that for direct light, but without taking into account Lambert's law for vertical angles, and plotted for the point

Up to the present little experimental work has been done on the subject of diffused light. Measurement in ordinary rooms is somewhat unsatisfactory, partly because of the unknown effect of furniture and the necessity for removing all glazed pictures and mirrors, but chiefly on account of the effect of the observer himself, who must of necessity stand near the test card, and whose clothes are illuminated to a different degree of brightness at different parts of the room. It is suggested that a more satisfactory method of investigation would be to make use of

small models, which can very easily be re-papered in a few minutes, in connection with some form of artificial sky such as a large hemispherical opal glass shade exposed to the ordinary sky or to some powerful and well-diffused source of artificial light. In this way it would seem probable that experimental work might be greatly expedited, and many errors of observation might be eliminated which are unavoidable when the observer has to rely on natural sky, and has to stand inside a room or model room.

Horizontal Illumination.

As stated at the commencement of this Paper, the whole of the foregoing is directed to the measurement or predetermination of light falling on a horizontal plane, and reflected back into our eyes in a more or less vertical direction. The amount received horizontally, reflected from vertical planes, can probably be predetermined and measured by methods similar to the above if due allowance be made for the different effect of Lambert's cosine law,

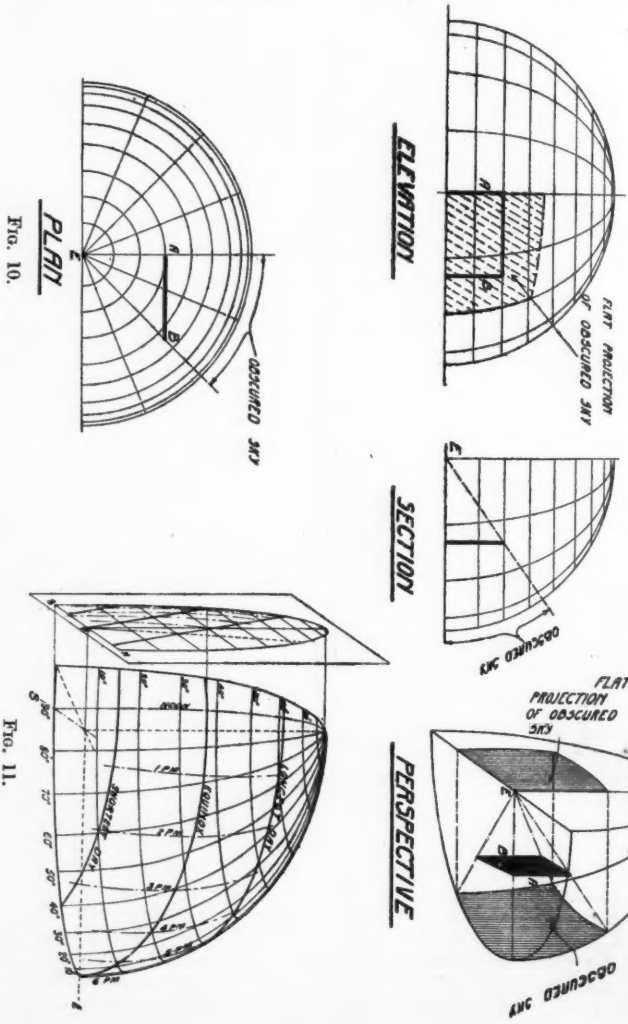

Fig. 10.

Fig. 11.

which requires that we attribute a decreasing instead of an increasing relative value to different areas of sky as their elevation increases. This correction can readily be made for direct illumination by projecting on to a measuring diagram of the character of Fig. 22, in which the vertical angular divisions are so set out as to decrease the value of high angle sky in proportion to the square of the cosine of the angle of elevation. The cosine must be applied twice over as a reducing factor, for two reasons: first, because of the geometrical fact, already referred to, that the area of sky which is obtained for one vertical "degree's worth," decreases according to the cosine of the angle of elevation; and secondly, because Lambert's law now acts in the opposite direction, so that the value of a degree's worth of sky is further reduced on account of its obliquity in proportion to the same cosine.

In addition, Lambert's law must be applied to the horizontal angles, since a vertical surface, unlike a horizontal plane, is illuminated to a less extent by lateral light.

It happens that the projection of the hemisphere used in sun diagrams (see Appendix I.) has a correct area scale for illumination on a vertical surface, but it is less convenient in use than a diagram of rectangular form (see Appendix II.).

Sunlight.

The access of sunlight to streets and interiors is a subject of great importance, but the unavoidable length of a Paper dealing with daylight has enforced its restriction to a short description given in Appendix I. of methods by which the hours of possible sunlight through any aperture at any aspect can be ascertained.

The whole of Appendix I. has appeared in the Transactions of the Surveyors' Institution, and is reproduced therefrom by the kind permission of their Council.

SUMMARY.

The only existing methods for predetermining windows are certain well-known rules which purport to determine the area of glass as a proportion of the floor area lit, possibly modified by keeping the window head at a minimum height determined by the depth of the room. Such rules, if correct for cases in which the obstruction of neighbouring buildings is negligible, must necessarily be incorrect for obstructed windows, for any obstruction necessarily alters the essential properties which enable a window to illuminate a room. These are:—

(A) The area, angular height and possibly the aspect of the visible sky at the back of the room or at the worst lit position in the room—which determines the minimum daylight factor due to direct light from the sky; and

(B) The amount, and possibly the aspect, of the visible sky subtended at the window, which, in conjunction with the colour of the walls and ceiling, determines the contribution to be made to the minimum daylight factor by diffusely reflected light.

The term "visible sky" includes, of course, due allowance for any obstructions which can appreciably reflect light.

In the large majority of cases windows can be designed with much the same confidence as that which we should have in sailing a boat in the middle of a tidal estuary without fear of running aground. It is only when we get into the shallows that we feel the need for charts, soundings and tide tables.

Except in crowded towns, it is generally not difficult to light all interiors adequately by means of windows of moderate size and height without spoiling the balance of fenestration in adjoining elevations or incurring the disadvantage of excessive glass area.

This is rather apt to engender in the designer a misleading sense of ability to deal with all situations which may occur. It is only when he encounters cases of severe sky obstruction coupled with deep rooms and the necessity or desirability of retaining a small window area that he feels the need of more exact methods of predetermining daylight problems, for a mistake, once made, is generally irrevocable.

The object of this Paper is to supply that want. It is assumed that the dimensions of the interior, the window and the obstructions have all been fixed, and that it is necessary to ascertain whether those conditions will result in an adequate daylight factor at the worst lit point, or at any number of doubtful points in the interior.

It is thus at present mainly a trial and error method, although, with its help, it may prove to be possible at a later date to formulate general rules giving the window dimensions necessary under any combinations of circumstances, although the labour involved will necessarily be heavy.

The following summary of the operations necessary in any particular case will serve to indicate their simple character :—

(1) *Direct Light.*—From the worst lit positions in the given interiors, or from any number of doubtful positions, the sky visible through the window, windows or skylight over any obstructions which may be present is plotted by its angular co-ordinates on a suitable measuring diagram, representing the quarter sphere of visible sky. The divisions are so adjusted as to represent by the area any piece of the visible sky its power of illuminating a surface at the point under consideration. This plotting can usually be done from the plans and sections, but the rather tedious work involved can be greatly reduced by the judicious use of simple trigonometry.

The direct light factor is then obtained by comparing the area of visible sky with the area of the diagram.

(2) *Diffused Light.*—To the above must be added the contribution made by diffusely reflected light. We certainly require much more and much better data of this, but it can generally be estimated as lying between the limits of 1 per cent. (sill ratio) in the case of exceptionally shallow rooms with large windows and nearly white walls, about 0·4 to 0·5 per cent. in ordinary rooms with light walls and ceilings and small obstruction, and well below the grumble point of 0·4 per cent. sill ratio when the obstruction is material.

(3) *Sunlight.*—The hours of possible sun which can enter the room can be ascertained by similar methods described in Appendix I.

If the result is insufficient or excessive, the diagrams show at once in what particulars any of the assumed conditions can most effectively be varied.

In conclusion, it should perhaps be emphasised that methods of measurement only serve to assist our judgment—they will not do our thinking for us. The clinical thermometer helps the doctor to use his medical knowledge and experience with more assured accuracy, but it does not supply the place of either qualification, for no two cases are exactly similar.

However great, therefore, may be the degree of accuracy to which we may bring methods of measuring and predetermining daylight, they can never take the place of intelligent observation, experience and judgment, for no two cases ever present the same features.

The undue length of this Paper may perhaps be forgiven when it is realised how wide is the gap between the mere measurement of daylight illumination in existing rooms—which is the limit of our present published knowledge—and any accurate solution of every-day problems, such as window design, especially if the methods adopted are to be simple and straightforward.

This Paper does not purport to lay down dogmatic rules as to how that gap should be bridged; it merely suggests a simple method of bridging it.

The authors have endeavoured to describe the proposed structure complete with all its details and calculations. They trust that your critical examination of it will be both searching and thorough.

The improvement of cases of bad lighting.

Although in this country we are still protected from the more ghastly results of sky-scraper building, a typical example of which will be found in the Proceedings of the American Illuminating Engineering Society, Vol. IX., p. 646, yet cases of bad lighting can undoubtedly be found in many of our older industrial buildings. The typical modern factory has usually plenty of glass area. Some, in fact, appear to have too much, the glazed openings being unnecessarily large, and extended to positions where no useful light can enter.

It is quite possible to reduce the solid walls of a factory to a point where even exorbitantly expensive warming and ventilating plant will not suffice to keep the rooms reasonably warm in winter and healthily cool in summer.

But even these evils are preferable to the poky and often dirty little windows of the typical early Victorian factory. One finds only too frequently in palatial blocks of City offices back rooms devoted to clerks and typists, who have no trades union and no factory

inspectors, most inadequately lit from light wells which the architect has been tempted to reduce to insufficient dimensions for the sake of additional floor space. It is true that such light wells are generally faced with white glazed bricks and occasionally they are cleaned. But even if such glazed walls could reflect 100 per cent. of the light incident on them and were kept perfectly clean, they could never equal the sky which they replace. A glazed wall facing South would certainly be in a position to reflect light from a portion of the sky which, *on fine days*, is of a greater average brightness than that which is opposite to a window facing North. But it is on dull days, not on sunny days, that the mischief is done. Even the best glazed facings waste some 20 per cent. or more of the light which falls on them in the process of reflection when clean, and considerably more when neglected. Also they can generally receive light from only a small portion of the sky, and are therefore necessarily much darker than the sky itself. In addition they are often cut up by windows, the glass of which reflects practically no useful light.

The improvement of cases of bad natural lighting is invariably attempted on the general lines of making the most of what sky is left. Light coming from the sky at too steep an angle to enter the window or at least to penetrate far into the room is caught on inclined mirror reflectors placed outside the window and directed more or less horizontally into the room.

The same effect is obtained by the use of prismatic glass either glazed in the window sashes or used in the form of independent outer sashes inclined at a suitable angle to effect the desired refraction.

Much care has been directed to the production of these prismatic glasses, of which some excellent kinds (Luxfer, Pilkington's, etc.) are on the market, and when properly installed they can undoubtedly effect remarkable improvements in the lighting of basements and of rooms at the bottom of deep light wells.

Where light is required mainly in a horizontal direction as in basement stores, they are excellent; but for clerical work the unnaturally horizontal direction which they give to the light and their tendency to specular reflection and glitter is undoubtedly bad, and rooms lit with them should always be so arranged and furnished that the occupants shall normally work with a side light.

APPENDIX I.

SUNLIGHT.

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The determination of the number of hours of sunlight which will on fine days enter a room through a given aperture is a more simple problem than that of the daylight illumination which can be obtained through the same aperture. The simple case may be taken of a window on a vertical wall lighting a room, the horizon being partly obstructed by buildings. The point in the aperture through which light can enter over a maximum number of oblique directions, horizontal and vertical, is first obtained by finding the intersection of planes touching the inner and outer reveals. It is assumed, as in Fig. 10, that the sky opposite the window is a quartersphere, of which this point is the centre. Any rectangular obstruction will block out from the view of a window an area of sky of which the flat projection necessarily appears to be distorted. A flat projection of this quartersphere of sky is described, of any convenient radius, say 10 in., and divided up into convenient angular divisions by lines of celestial latitude and longitude (Fig. 11). Upon this flat projection are projected planes generating at the centre point and touching the reveals and head of the window, giving the total sky visible from that point in the window aperture which can receive light from the maximum number of directions. Similar planes touching the edges of obstructing buildings are also projected, so that the area left between such projected planes and those of the window opening represents the total visible sky. All that is then necessary is to trace across such

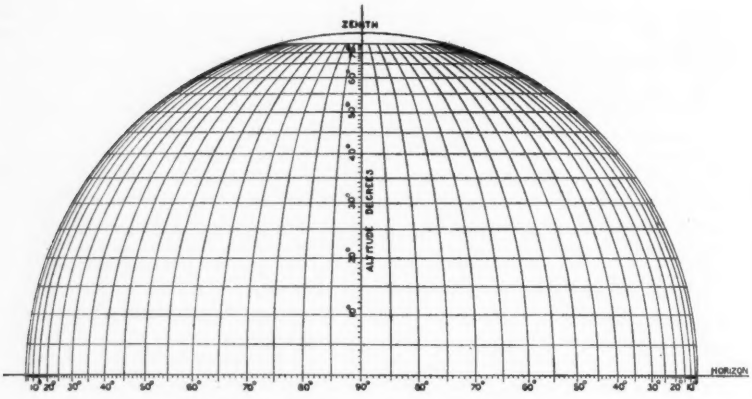


FIG. 12.—Flat projection of quartersphere.

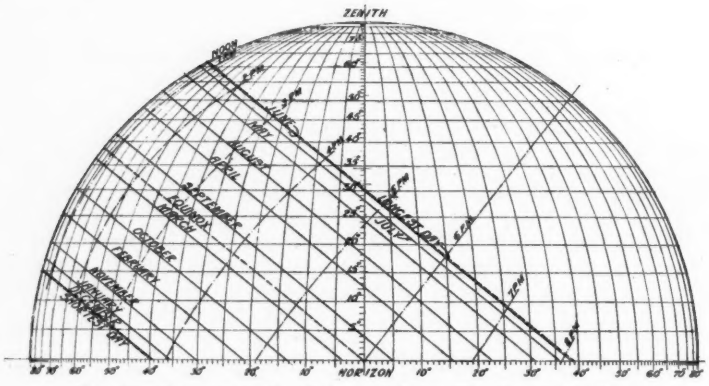


FIG. 13.—Apparent path of the sun facing W. Latitude 51° 31′ N.

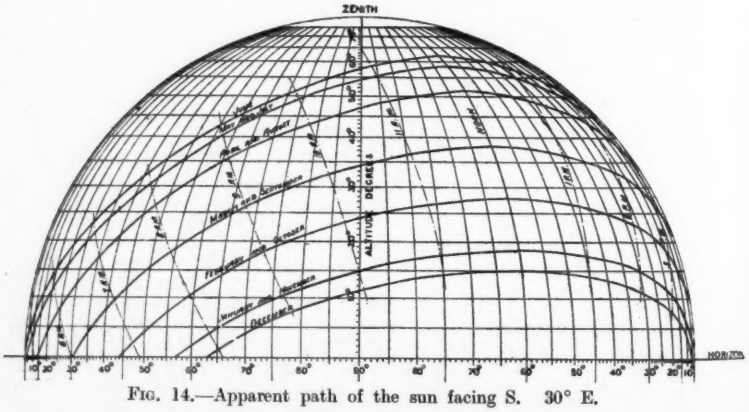


FIG. 14.—Apparent path of the sun facing S. 30° E.

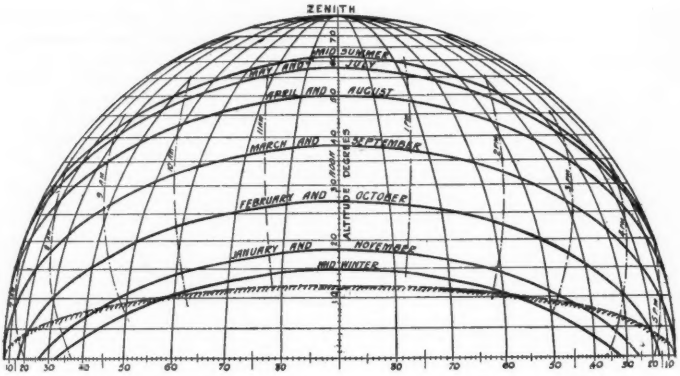


FIG. 15.—Apparent path of the sun facing S. Latitude 51° 31′ N.

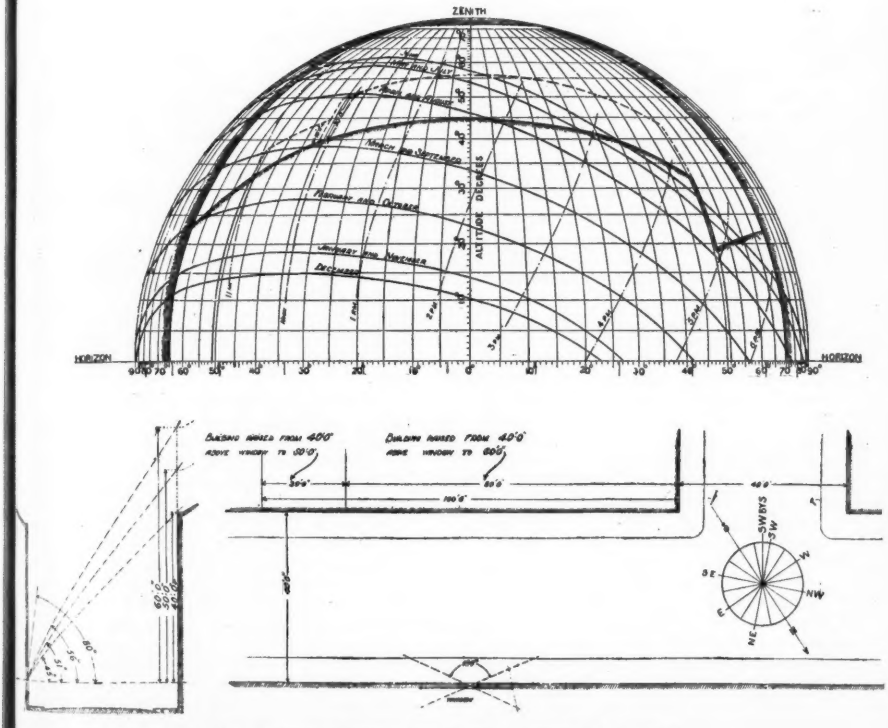


FIG. 16.—Diagram showing loss of sun. Aspect S.W. by S.

visible sky the apparent paths of the sun at different periods of the year, such as midsummer, midwinter, and the equinoxes; or, say, the 15th of each month, and to mark on these solar paths the points which the sun apparently passes at different hours of the day. The solar diagram, of which Fig. 16 is an example, shows at once the daily periods over which the sun can shine into the room through the aperture under consideration, and the prolongation of the sun paths across the obstructions, existing or proposed, shows similarly the loss of possible sunshine.

The following method of describing solar paths was adopted from that described in Molesworth's "Obstruction to Light," and will be found to be quite simple.

If the heavens be considered as a great sphere, the apparent diurnal path of the sun across that sphere will always be a circle inclined to the horizon, which circle the sun traverses once in 24 hours, or at the rate of 15° per hour. In the sun diagram, the sphere, with the sun paths traced on it, is supposed to be projected on to a flat plane, as in Fig. 11, and the direction in which the sun paths are seen is determined by the aspect of the diagram; since these paths are circular, their projections will always be either straight lines or portions of ellipses.

Viewed in a due east or due west direction, as in Fig. 11, these circular paths are seen on edge, and in consequence their projections become straight lines, giving the diagram shown in Fig. 13, which shows a due west aspect with south (noon) on the left and north on the right.

In setting out a diagram, a tracing of the flat projection (Fig. 12) is used. If this be employed for an east or west diagram, it will be obvious that the noon altitudes, being south and therefore on the edge of the diagram, can be marked on the circumference in degrees above the horizon. At noon at the equinoxes the sun is at a height above the horizon equal to the co-latitude 90° — latitude, and at 6 p.m. it is at the horizon due west, at the centre of the diagram. A straight line joining these points gives the apparent equinoctial afternoon sun path. The noon altitude for any other day in the year can be found by adding to the equinoctial noon altitude the "declination north" given in Whitaker or the Nautical Almanac for each day in the summer from March to September, and by deducting the "declination south" similarly given for each day in the winter from September to March. From these noon altitudes the apparent sun paths at dates other than the equinoxes, viewed in a due east or due west aspect, may be described by drawing straight lines parallel to the equinoctial line from noon to sunset.

Since the sun traverses the equinoctial sun path at a uniform rate of 15° per hour, this path can readily be divided into hours and, if necessary, minutes, reckoning 15° per hour or four minutes of time to 1°. The equinoctial path is, like the base line of the diagram, a great circle of the sphere, and the paths for other times of the year are exactly similar to the parallel lines of celestial "latitude" drawn horizontally across the diagrams. By the construction of the diagram these lines are already divided into angular divisions by the curved lines of celestial "longitude," so that any required divisions of time can readily be transferred to the sun paths for any period of the year in an east or west aspect by means of a tracing of the lower 22½° of the projected hemisphere, and of the similar 22½° below the horizon (Fig. 12).

A due east or west diagram being now complete, a similar diagram for any other aspect can readily be obtained from it simply by shifting any number of convenient points on the straight line paths to the right or left by the number of degrees between the aspect required and due east or west. For instance, a south-west aspect is 45° to the left of a due west aspect and 135° to the right of a due east aspect. A south aspect is 90° to the right or left, and upon such a diagram (Fig. 15) it will be seen that the points on the equinoctial sun path shifted 90° across the diagram result in a complete semi-ellipse.

For drawing the elliptical paths of other aspects and times by joining up transferred points, large French or ship curves will be found to be more convenient than railway curves. Fig. 16 shows the application of these methods to an actual case.

Solar path diagrams will be found to reveal quite a number of unexpected points. They show, for instance, how very much lower the sun is as compared with what it appears to be. A winter elevation which only reaches 15°, and a summer elevation which only climbs up to its maximum of 62½° at noon on midsummer day are both much lower than would be estimated by most people. The amount of possible sun from a north-eastern, or north-western, or even a northern aspect, is somewhat surprising. Sun diagrams also show that a due south aspect is not necessarily the most sunny with obstructions in front, especially in a long street of moderately high houses. Above an obstruction of 45° directly opposite to a window only mid-day

summer sun can enter, but in all oblique directions an obstruction of the same height subtends an increasingly smaller angle, as its distance increases with the obliquity. An obstruction which would subtend 45° directly in front of a window subtends only 36° in directions inclined to 45° to the right or left, whilst at an obliquity of 60° it drops down to 30°. Obviously, therefore, more sun will be enjoyed over an obstruction if the aspect be south-west or south-east, in which the position of the mid-day sun will reach its maximum elevation further along the street, where it will coincide with the more distant and therefore less severe obstruction.

The method of constructing the diagram from the point which is most favourably situated to receive very oblique rays credits the window with ability to pass rays which can only enter a very short distance into the room. In view of the very great gain in cheerfulness which all parts of a room enjoy when even a very oblique ray of sunshine enters the window, this is perhaps not altogether unreasonable. But if it were desired to ascertain the hours of possible sunshine which would reach any particular point inside the room, such as a hospital bed, or, in the tropics, an instrument or piece of machinery upon which the sun cannot be allowed to shine for more than a short period every day, then a diagram for that particular point must of course be described.

APPENDIX II.

Pleier's Formula for the Reduced Square Degrees of Sky visible through any Window.

It has already been shown that the lighting value of any small piece of sky is proportional to (i.) its brightness, (ii.) its average angular elevation, and (iii.) the solid angle which it subtends; *i.e.*, the lighting value is proportional to

$$B\omega \sin\theta,$$

where B is the average brightness, ω is the solid angle subtended, and θ is the average angle of elevation.

For very small elements of sky, the term $\omega \sin\theta$ is the "reduced square degrees" of sky. In Pleier's formula, the principle has been applied to the whole patch of sky visible through the window.

Referring to Fig. 17, and using the notation there shown, if A be the part of the window through which sky can be seen, from a point O, then

Area of $A = ah$.

Area of A projected normally to $OA = ah.\cos OCD.\cos AOC$;

$$= ah \frac{OC}{\sqrt{m^2+n^2+o^2}} \cdot \frac{m}{OC}$$

The solid angle

$$= \frac{ahm}{(m^2+n^2+o^2)^{3/2}} \text{ steradian}$$

or

$$\frac{3283\,ahm}{(m^2+n^2+o^2)^{3/2}} \text{ square degrees.}$$

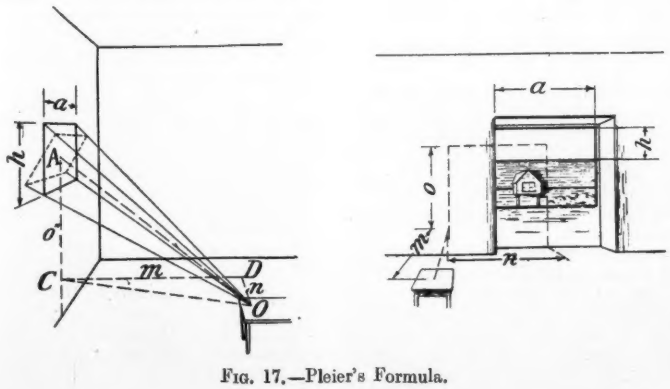


FIG. 17.—Pleier's Formula.

The "reduced square degrees" are approximately

$$\frac{3283\,ahm}{(m^2+n^2+o^2)^{\frac{3}{2}}} \cdot sin\ COA$$

or

$$\frac{3283\,ahm}{(m^2+n^2+o^2)^{\frac{3}{2}}} \cdot \frac{o}{\sqrt{m^2+n^2+o^2}}$$

or

$$\frac{3283\,ahmo}{(m^2+n^2+o^2)^2}$$

—(ILL. ENG., Lond., 1914, Vol. VII., p. 361.)

Authors' Formula for Direct Daylight Factor.

The construction of a formula for the calculation of daylight factor is made in two parts, viz. :—(*a*) calculation of illumination from the unobstructed sky, and (*b*) calculation of illumination received through a given aperture; the formula for the value of the factor is obtained by the division of one result by the other.

(*a*) *Illumination from an unobstructed sky.* (*See Fig.* 18).

Consider the sky to be a large illuminated white hemisphere, of which the brightness is everywhere uniform and equal to that of a perfectly white surface receiving E foot-candles normally: let the radius of the hemisphere be R, and let the point of observation be at the centre of the hemisphere.

It is required to find the illumination received normally by a horizontal surface at the point of observation.

Consider an elemental zone of the hemisphere at an angular elevation θ, subtending a small angle $d\theta$ at the centre. The area of the element

$$= 2\pi r R d\theta$$

or $$2\pi R^2 cos\theta d\theta.$$

The normal candlepower of element

$$= 2\pi R^2 cos\theta d\theta \cdot \frac{E}{\pi}.$$

Vertical illumination at centre due to this element

$$= 2ER^2 cos\theta d\theta sin\theta / R^2$$

or $$Esin2\theta d\theta \text{ foot-candles.}$$

The illumination due to the whole hemisphere is then

$$E\int_o^{\frac{\pi}{2}} sin2\theta d\theta \text{ foot-candles}$$

or

$$-\frac{E}{2}\left(cos2\theta\right)_o^{\frac{\pi}{2}}$$

or, E.

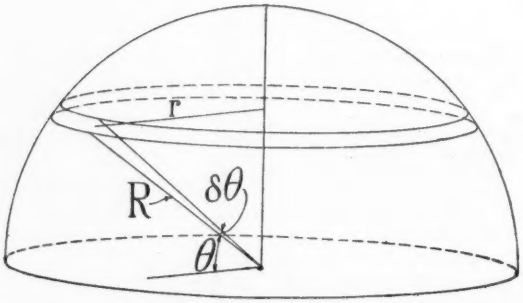


FIG. 18.—Illumination from hemisphere of sky.

Hence the brightness of a perfectly white card exposed to an unobstructed sky is equal to the brightness of the sky, and is equal to half that value when exposed to unobstructed sill light, *i.e.*, a quarter-sphere of sky.

(*b*) *Illumination through a rectangular aperture.*

In calculating the illumination through a rectangular aperture, such as a window in a vertical wall, we consider instead of the whole horizon, the horizontal angle subtended by the window at the point of observation; and instead of the whole sky from the horizon to the zenith, only that part which can be seen through the window from the point of observation, and integrate between the limits indicated by these angles.

Let the horizontal angle subtended by the window be φ, and the vertical angles θ_1 and θ_2 respectively.

(There is a slight error in assuming that the head of the window subtends a constant vertical angle; the sides being slightly further away than the centre, subtend a smaller angle, but this error is small and can be neglected.)

In Fig. 19, the width of elemental strip is $R.d\theta$, as before.

Length of elemental strip is φr, or $\varphi R.cos\theta$.

Area of elemental strip is $\varphi R^2 cos\theta d\theta$.

Normal candlepower of elemental strip is

$$\varphi R^2 cos\theta.d\theta.\frac{E}{\pi}.$$

Illumination from elemental strip is

$$\varphi cos\theta.sin\theta.d\theta.\frac{E}{\pi}$$

or

$$\frac{\varphi E}{2\pi}\cdot sin2\theta d\theta.$$

The whole illumination from the window is then

$$\frac{\varphi E}{2\pi}\int_{\theta_1}^{\theta_2} sin2\theta d\theta$$

$$=\frac{\varphi E}{4\pi}\left(cos2\theta_1 - cos2\theta_2\right)$$

Since the daylight illumination from a quartersphere is $\frac{E}{2}$, the daylight factor

$$=\frac{\varphi}{2\pi}\left(cos2\theta_1 - cos2\theta_2\right)$$

In the case of a window where observations are taken at sill level and there is no obstruction, the term $cos2\theta_1$ is constant and equal to unity; for windows with a distant obstruction it is nearly constant and less than unity.

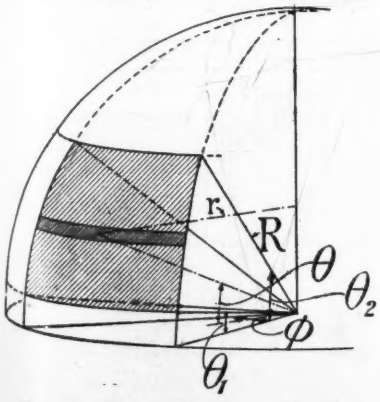


FIG. 19.—Illumination from rectangular window.

(c) *Construction of the diagram for the calculation of direct daylight illumination on a horizontal plane.*

It has been shown above that, for an unobstructed sky, when observations are taken at sill level, the direct daylight factor is proportional to $\varphi(1-cos2\theta_2)$.

Two points may be noted here; first, that the factor is directly proportional to the horizontal angle subtended by the visible sky. It follows from this that the scale of horizontal angles may be made even; it will extend of course from 0° at the centre to 90° on either side, so as to take in a complete quartersphere of sky.

Secondly, the factor is proportional to $(1-cos2\theta_2)$, thus giving the relation of the factor to the vertical angles. Imagine a "blind" placed over the quartersphere of sky and rolled up evenly from the bottom: the diagram representing the lighting value of the sky visible over 180° will be a rectangle having as base the full horizontal scale, the height being proportional to $(1-cos2\theta_2)$ where θ is the angle of elevation of the bottom of the "blind."

The method of constructing such a vertical scale will be apparent from Fig. 20. A rectangle is drawn to represent the whole quartersphere of sky, preferably having some convenient area such as 200 sq. ins. The base is divided up into 180 equal parts, representing the horizontal angles, and numbered from the centre; for the vertical scale, a semicircle is described on the vertical side of the rectangle, and the double angles (0° to 180°) are marked off on its circumference and projected across the diagram, as shown in the figure. It will be obvious that, if the radius of the circumference is taken as unity, the height of the horizontal line representing any angle θ above the base line will be proportional to $(1-cos2\theta)$, to that the area shown on the diagram representing a piece of sky extending over a horizontal angle φ and a vertical range $\theta_1-\theta_2$ will be proportional to $\varphi(cos2\theta_1-cos2\theta_2)$.

Hence areas on the diagram representing sky will be proportional to the values of such pieces of sky for lighting a horizontal plane surface.

(d) *Construction of the diagram for the estimation of diffused light.*

As in the case of the diagram for the estimation of direct light, imagine a similar "blind" rolled up from the bottom of the quartersphere representing the sky.

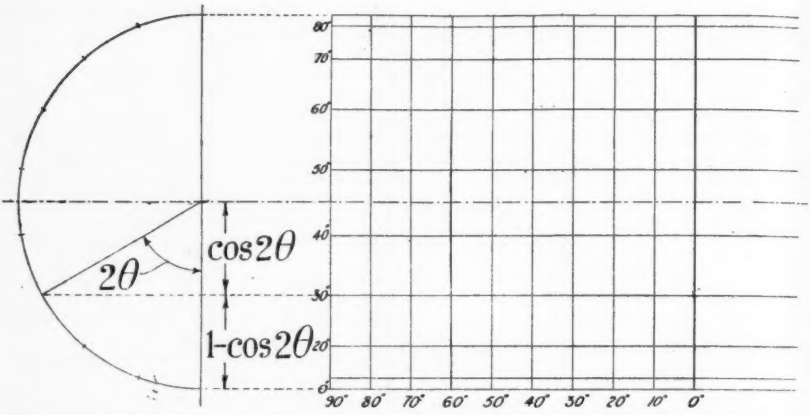


FIG. 20.—Construction of measuring diagram for direct light factor. Illumination measured vertical on a horizontal plane.

As has already been pointed out, there is now no need to take into account the angular elevation of the element of sky; the diagram is concerned only with its area.

Referring to Fig. 18, and using previous notation—

Area of the element is $2\pi r \cdot Rd\theta$, or $2\pi R^2 cos\theta d\theta$.

Illumination from element $2Ecos\theta d\theta$.

Illumination from hemisphere up to an angle θ_2

$$2E\int_0^{\theta_2} cos\theta d\theta = 2E.sin\theta_2.$$

Thus the height of the line representing an angular elevation of θ degrees must be proportional to the sine of the angle: the geometrical construction is obvious, and is shown in Fig. 21.

(e) *Construction of the diagram for the predetermination of direct horizontal illumination.* (See Fig. 22.)

In this case the theory is exactly similar to that used in the case of vertical illumination, but the sine term which comes from the application of Lambert's law to the vertical divisions becomes a cosine, so that the horizontal illumination from a zone up to θ_2 degrees elevation is now proportional to

$$\int_0^{\theta_2} cos^2\theta d\theta \text{ or to } \theta_2 + \tfrac{1}{2}sin2\theta_2.$$

The geometrical construction of the diagram, while not so simple as those for the other two diagrams, is quite easy. It must be remembered that θ is measured in radians, so that in setting out a circle in order to obtain the value of the term

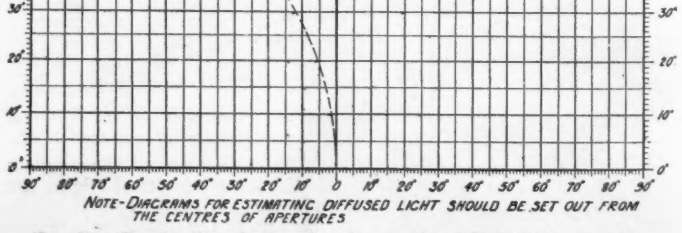

90° 80° 70° 60° 50° 40° 30° 20° 10° 0 10° 20° 30° 40° 50° 60° 70° 80° 90°
NOTE-DIAGRAMS FOR ESTIMATING DIFFUSED LIGHT SHOULD BE SET OUT FROM THE CENTRES OF APERTURES

FIG. 21.—Construction of measuring diagram for diffused light factor.

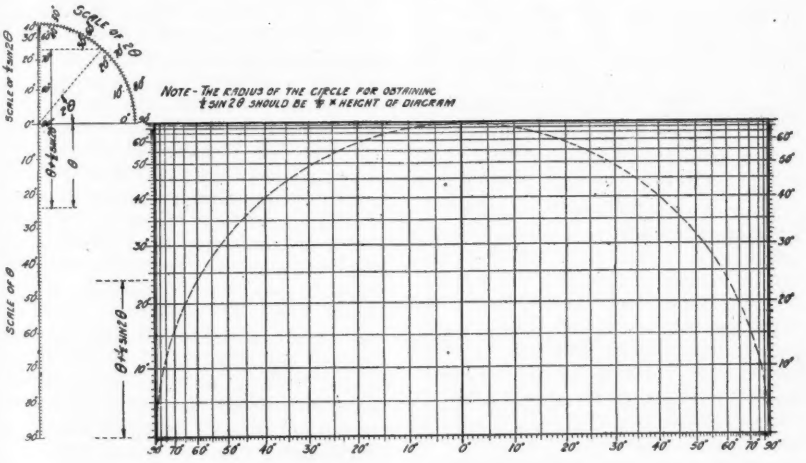

NOTE - THE RADIUS OF THE CIRCLE FOR OBTAINING ½SIN2θ SHOULD BE ½ × HEIGHT OF DIAGRAM
SCALE OF ½SIN2θ
SCALE OF 2θ
SCALE OF θ
θ+½SIN2θ
θ

FIG. 22.—Construction of measuring diagram for direct light factor; illumination measured horizontally on a vertical plane.

$\frac{1}{2}sin2\theta$ the radius of the circle must be such that the length of arc which subtends an angle θ shall be equal to the scale length which represents an angle θ, used in obtaining the first half of the expression.

In setting out the vertical divisions, the rectangle representing the boundary of the diagram having been drawn, a regular scale of angles from 0° to 90° is made, the total length of which is equal to the vertical height of the diagram. This gives the term θ. To this must be added the term $\frac{1}{2}sin2\theta$ for each angular division. A circle is drawn above the scale of θ, of such a radius that the arc which subtends an angle 2θ at the centre is equal to the length which represents an angle of $\theta°$ on the lower scale of angles. It will be seen that by setting out the double angles on this circle and projecting across on to the scale of angles produced, a scale of $\frac{1}{2}sin2\theta$ is formed. The distance between the division marked, say, 24° on the lower scale to the corresponding division on the upper scale gives the value of the expression $\theta+\frac{1}{2}sin2\theta$, and is the distance from the bottom of the diagram at which the line representing this angle must be drawn.

In addition, the horizontal divisions must be compensated for the effect of Lambert's law on lateral light; the value of each horizontal interval in illuminating a vertical surface is proportional to the cosine of its obliquity. The obvious construction is to describe a semicircle on the base of the diagram, to mark off the angles on its circumference and to project downwards on to the base.

DISCUSSION.

The CHAIRMAN (Mr. D. R. Wilson), in opening the discussion, said that the subject of the lecture was of special interest in two respects. First it dealt with the most ancient phenomenon in the world, daylight, proclaimed in the impressive words at the beginning of Genesis. Secondly, there had hitherto been a tendency for the consideration of the use of natural light to be somewhat neglected as compared with artificial; possibly one reason for this might be that in the case of artificial light we were concerned with the production of light, whereas in dealing with daylight, we were concerned with its adaptation. Nevertheless, the use of daylight was of very great importance, especially in industrial lighting where the shortening of hours of work had increased the proportion of time during which natural light was used.

Mr. J. W. T. WALSH (the National Physical Laboratory) said that he was full of admiration for the masterly way in which the authors had dealt with what was, as they stated, a distinct gap in the literature of illuminating engineering.

Of the deficiency of information of natural lighting he (Mr. Walsh) had had personal experience. They should be grateful to the authors, not only for the clear exposition of existing knowledge, but for the new suggestions contained in the paper in regard to the measurement and prediction of daylight illumination.

There were a few points on which he was not entirely in agreement with the authors, for instance, the method which they advocated for the determination of "daylight factors." The authors had remarked, very truly, that the important part of the sky to consider was that immediately opposite the window, from which the illumination at the point of test inside the room was derived. They accordingly suggested that the best procedure was to measure the illumination in the room, and then to point the instrument at the sky and measure its brightness, making due allowance for the absorption of light by the window-glass. But the method had disadvantages in practice. There were many cases in which windows were not readily accessible and could not be opened; nor could the amount of dirt left on them since the last time of cleaning be gauged with any accuracy. Conditions were specially difficult in the case of a room lighted entirely by skylights, and there were also cases in which, owing to the obstruction of neighbouring buildings, one could not get any proper glimpse of the sky from inside the room. He thought, therefore, that in spite of obvious difficulties the best method of measuring the daylight factor was that most generally adopted, namely, either to measure the illumination on a horizontal surface on the roof or other accessible open position, or to ascertain the illumination outside the window-sill.

He was much interested in the formula proposed by the authors for determining the direct daylight factor. He had checked this and found their simplified formula quite sufficiently correct for all ordinary purposes.

Mr. G. F. COLLINSON, F.R.I.B.A., briefly expressed his interest in the paper, and drew attention to the variations in brightness of direct sunlight, as compared with light from a white sky.

Mr. R. LANGTON COLE, F.R.I.B.A., said that he fully agreed as to the importance of the method of measuring access of daylight described in the paper, and he was aware that Mr. Waldram's use of it had proved a formidable weapon in "ancient light" cases. There were one or two points in the paper that he would like to discuss, firstly, whether the most expeditious method of ascertaining the degree of obstruction from neighbouring buildings would not be to take a photograph, showing the sky-outline, through the window? He understood Mr. Waldram to say that the value represented by the "daylight factor," on the worst-lighted desk in an elementary school-room, only about one per cent. was in the form of diffused light. It seemed to him doubtful whether even one per cent. of the total outside illumination could be obtained by diffused light alone, and without any direct light from the sky.

Mr. WALDRAM, interposing, explained that the light found on the worse lit desk of an elementary class-room was one per cent. of the light falling on a window-sill with a clear horizon. Of this about half would be contributed by direct light from the sky, and about half by light diffusely reflected from walls and ceilings.

Mr. LANGTON COLE, continuing, remarked that in cities many buildings received very little more than diffused light. He assumed that in "ancient light" cases no legal consideration could be given to the effect of bars and frames, and the make-up of the window generally, and that the opening was regarded as being clear of all obstructions, even glass. Hence the measurement of frames, etc., would seem to be beside the mark as regards "ancient light" cases, though it was doubtless useful in general determinations of access of daylight. He would also like to know whether the mathematical conception of the sky as a luminous hemisphere or quartersphere was entirely borne out by results in practice.

In conclusion, he wished to join in the general expression of appreciation of the contents of the paper.

Mr. J. MACINTYRE (H.M. Office of Works) remarked that in a crowded area such as London architects had a very

difficult task, faced as they were by financial restrictions to crowd as much building as possible into the available space. He had little doubt that, even taking these circumstances into consideration, the best use was not made of daylight in many cases, and he hoped that the subject would be followed up by architects, so that there would be a cessation of the tendency to advocate overcrowding of buildings and more attention given to fenestration from its utility aspect. Even in the case of buildings in which there are no obstacles in front effective daylight was frequently sacrificed unnecessarily to the design of the elevation which a full knowledge of the subject on the part of the architect would have prevented.

He would welcome some information from Mr. Waldram on the subject of designing rooms to be illuminated from light-wells. The cost of glazed brick for use in rooms facing light-wells was an important item, and he hoped that the lecturer would add something on the merits of various methods and the relative dimensions of windows and rooms necessary for good illumination. The chief difficulty in the use of prismatic glassware was that the glass became dirty and the cost of cleaning was considerable.

Mr. A. BLOK referred to the loss of light through dirt on windows. It would be interesting to have fuller particulars of the extent of this loss under practical conditions. He recalled some experiments he once made in a central block of offices in the City of London where it was the practice to have the windows cleaned once in two months. He had found that an accumulation of dirt during two months in this locality actually diminished the illumination in the room by about 25 per cent. The matter was of importance because it was lamentable that after a numerical result had been arrived at by such ingenious methods the result should be subject to such considerable deterioration owing to accumulation of dirt on the glass. He endorsed the remarks that had been made by other speakers in praise of the paper.

Mr. W. R. RAWLINGS also mentioned the question of absorption of light by dirty window-glass, and expressed the hope that Mr. Waldram would furnish particulars for the specimens on the table. If such figures could be included in the printed account of the proceedings they would, he thought, add to the value of the paper which contained such a useful survey of daylight illumination.

Mr. L. GASTER said that the paper had contained an admirable summary of recent work on daylight illumination, besides new suggestions for the measurement and predetermination of daylight in buildings. Reference was made in the paper to the work of the joint committee of the Society on Daylight Illumination in Schools, of which Mr. P. J. Waldram is a member. The Committee was regarded as having done useful pioneering work, and he would like to see similar co-operation between photometric experts and members of the architectural profession in dealing with daylight conditions in buildings generally.

Reference had recently been made in THE ILLUMINATING ENGINEER to an important " ancient light " case in Bradford, where the record of tests conducted by Mr. Waldram had had an important influence in determining the decision. The case furnished a gratifying instance of the growing recognition of the value of scientific measurements in connection with daylight problems.

There was one point that had occurred to him when examining the samples of window-glass shown by the authors. It was evident that deposits of dirt might occasion considerable loss of light and that window-glass should be cleaned at regular intervals. But in many large factories, having very extensive areas of glass, the cost of cleaning was a heavy item. It would therefore be useful if some indication could be given—either in the form of a limit to the absorption of light by the dirty glass or its influence in reducing the " daylight factor "—when a point had been reached such that cleaning of the glass was essential. This point should be borne in mind in any regulations affecting cleaning of windows.

The CHAIRMAN (Mr. D. R. Wilson), in moving a vote of thanks to the authors, said that all would agree that they had listened to a most interesting and instructive discourse. The paper contained a

great deal of valuable information and had almost led him to modify the view he expressed in his opening remarks to the effect that the study of daylight had been unduly neglected. It would, perhaps, be more correct to say that although the subject of daylight illumination had been very carefully studied by a few investigators, it had been less widely investigated than artificial light.

Mr. P. J. WALDRAM in replying to the discussion, expressed the thanks of the authors for the reception which had been accorded to their paper. The remarks of Mr. Walsh in particular had ended pleasantly a long period of anxiety for his son and himself. Natural illumination was of the greatest importance to health, especially industrial health, and affected enormously the cost of building, but methods of predetermining it had, he believed, never before been attempted, at least comprehensively. For this reason any precise rules, formulæ, and methods, such as were laid down in the paper would of necessity have a very wide application; and would attract and even demand very close scrutiny and the most searching criticism.

When to this was added the fact that the authors had been forced to depend upon improvised apparatus for the severe tests which were required to prove every step in their work it was, perhaps, pardonable if they should have been somewhat apprehensive as to the result of the trial of their methods by the almost unlimited resources of the National Physical Laboratory; where similar researches were being carried out in a building especially designed for the purpose.

They had, therefore, heard with no small relief Mr. Walsh's generous remarks, and the gratifying results of his tests; the more so because they were assured that a scientist of his attainments and record would never allow his judgment to be influenced either by the Teddington tradition of courteous co-operation with outsiders or by his own generosity.

Mr. Walsh's reference to what he termed the authors' "simplified formula," which he had found to be applicable to a square aperture with only a negligible error, might perhaps convey the impression that they had risked accuracy in order to attain simplicity. This was not so. The short formula giving the illumination from a piece of sky of definite angular dimensions was used by them only for its legitimate purpose, viz., to produce accurate measuring diagrams. Openings of any shape, however irregular, projected on to these diagrams indicated the direct daylight factors at once by their projected area without any calculation whatever. It should be mentioned that the fundamental formula which had rendered these diagrams possible was entirely the work of his son.

Previous to their production the labour of correcting for Lambert's law on a simple projection of a hemisphere of sky in ancient lights cases had been almost interminable; now it was a mere draughtsman's job.

He noted that Mr. Walsh still preferred the hemisphere or "roof ratio" method of measuring existing conditions of daylight because it was applicable to situations where no direct sky was visible, or in which it was impossible to open the windows. Under such exceptional conditions one would naturally use the best method possible, but there were often cases where no unobstructed roof was accessible, and he was inclined to the opinion that the "sky brightness" method would render measurements possible in many more cases than the few in which only roof or sill measurements could be taken, and that whenever it could be used it was more accurate, less liable to error, and much more convenient than either roof or sill measurements. When one had to visit a distant provincial town, take measurements and return on a winter day on the eve of an important ancient lights case it was often invaluable. They hoped in the near future to simplify it still further, and he would be grateful for any information from Teddington on the reflection coefficient of Lumeter cards, or of some standard make of white blotting paper.

Mr. Langton Cole was quite correct in assuming that the most expeditious method of obtaining the area of sky visible from any point through a partially obstructed opening was by means of a

photograph taken at the point. But it was necessary to know the exact focal length of the camera, and to take the photograph through a transparent mask indicating the lines of angular deviation, horizontally and vertically, from the optical centre of the picture. Where permanent records were not required an expeditious method of setting up diagrams was that referred to in the paper in which the ground glass focusing screen was marked out with pencil lines of angular deviation. The diagrams of existing conditions obtained with the help of such a camera could, of course, readily be co-ordinated with suitable perspective views of any new conditions. In reply to Mr. Langton Cole's inquiry as to the accuracy with which results predetermined by the authors' method corresponded with actual measured results, they might be expected to agree within say 10 per cent. Generally it was his experience that if the measured results in an ancient lights case seriously failed to agree with the predetermined results there was either something wrong with the measurements, or else the drawings which purported to indicate the conditions to be predetermined proved upon re-measurement to be inaccurate. He did not agree that a plaintiff in an ancient lights action could claim all the light which came through an opening without window frame, window bars, or glass. He believed that the shuttering or boarding up of a window for over twelve months during the period of 20 years over which prescription was accruing had been held to be no bar to a valid claim; but he strongly doubted whether the courts would allow a plaintiff to claim for the uninterrupted capacity of an opening which he had consistently reduced himself by, say, stained glass; or alternatively would grant damages in respect of a diminution in the lighting capacity of a window which was materially less than any unnecessary diminution which the plaintiff himself had consistently inflicted upon it.

The very important subject of illumination from light wells mentioned by Mr. Macintyre was sufficiently wide to require a paper of its own, and more data was required than was at present available. Rules for windows could, of course, be formulated preferably in the form of contour diagrams of illumination for rectangular unobstructed openings of a given proportion of width to height and wall thickness; the distance of the contours from the window being in terms of the width or height of the window. It would also be feasible to calculate additional sets of diagrams for varying degrees of obstruction, say, 40°, 50°, and 60°. But in actual practice one usually found obstructions, old and new, which were far too irregular to be reduced to any given horizon, and it was difficult to conceive of data which would be sufficiently comprehensive to enable even ordinary cases to be determined without a prohibitive amount of interpolation. Still, the authors had the matter in hand, and would certainly publish any diagrams or tables which might promise a sufficient field of usefulness.

The loss of 25 per cent. due to dirt mentioned by Mr. Blok was certainly not abnormal; really dirty windows could absorb much more. It was scarcely feasible to incorporate in the proceedings the absorptions measured and marked on the glass specimens which they had exhibited, but he might mention that ordinary clear sheet glass absorbed about 7 per cent. to 10 per cent. of incident light when clean, and good plate including rippled or figured plate through which no clear image could be seen had been improved up to a transmission ratio of about 95 per cent. But these values fell off rapidly unless the glass were kept clean—probably at the rate of 10 per cent. per month at least even if the inside were kept clean and there were no large or numerous factory chimneys near.

The question of regulations for glass cleaning was a difficult one. In a factory where the daylight available at the working positions was below the average for the industry it was very desirable that the glass should be cleaned frequently; but factories which had larger windows, less obstruction, or, what was more important, made such good use of the sky they had that the daylight ratios of working positions were well above the normal, could afford to allow dirt to accumulate for longer periods.

On the whole he thought that if window cleaning were made compulsory it would probably be found preferable to specify periodical cleaning rather than any definite loss of daylight ratio. The compulsory period should obviously be less for workrooms or factories which had working positions with insufficient or no direct light from the sky or where the atmospheric conditions were bad.

Unfortunately, also, it would probably be considered that only very lenient conditions could be made compulsory. Cleaning once in three months, for instance, would be better than no cleaning in three years; but in many situations cleaning once a month would hardly be sufficient.

Mr. J. M. WALDRAM, replying to a further query by Mr. Langton Cole, said that it was correct to represent the sky, for purposes of calculation, by any surface which would fulfil the condition that some portion of it could be seen in any direction above the horizon. For instance, the sky could be satisfactorily represented by a horizontal plane of infinite extent, or by a variety of other surfaces. The hemisphere had been used merely for convenience in working with angular co-ordinates; and the method of applying the lines of celestial latitude and longitude to the hemisphere for the purposes of measurement did not affect at all the accuracy of the representation of the sky by a hemisphere.

THE INFLUENCE OF DAYLIGHT ILLUMINATION ON THE USE OF ARTIFICIAL LIGHT.

THE suggestion has often been made that ultimately an apparatus might be devised which would automatically give warning when the daylight illumination fell to a certain value rendering artificial light necessary. It has usually been assumed that such apparatus would be based on the use of a selenium or other type of photo-sensitive cell. But according to a paper by Mr. A. Smirnoff before the Illuminating Engineering Society in the United States* a useful indication is furnished by records of solar radiation obtained by a Callendar receiver and Wheatstone bridge recorder.

Measurements of daylight illumination, simultaneously with records of solar radiation were made and it was found that one gramme calorie per min. per sq. cm. corresponds roughly with full daylight illumination of 6,000 foot-candles. The illumination-equivalent with the sun at different altitudes was also worked out.

It is suggested that such records may be of considerable assistance to electric supply companies in enabling them to prepare for any sudden increase in the lighting load owing to unfavourable climatic conditions occasioning a fall in daylight illumination and more use of artificial light. It was found that a marked increase in current-consumption occurred as soon as full outdoor daylight illumination fell below 1,500 foot-candles. In general this would correspond to about 9 foot-candles six feet away from the window. With lower illuminations the increase in the use of artificial light became more marked; for full daylight illumination above 1,800 foot-candles effects of climatic variations were negligible. It is, therefore, proposed that recorders of solar radiation should be placed at outlying stations so as to give warning of any storm or clouds developing which would lead to an increase in the load. A relay could then be arranged to ring a bell when the record of solar radiation fell to a value corresponding with 1,500 foot-candles.

* *Trans. Illum. Eng. Soc.*, U.S.A., Jan., 1923.

TOPICAL AND INDUSTRIAL SECTION.

[At the request of many of our readers we have extended the space devoted to this Section, and are open to receive for publication particulars of interesting installations, new developments in lamps, fixtures, and all kinds of apparatus connected with illumination.

The contents of these pages, in which is included information supplied by the makers, will, it is hoped, serve as a guide to recent commercial developments, and we welcome the receipt of all *bona-fide* information relating thereto.]

AIDS TO DAYLIGHT ILLUMINATION.

In modern factories the importance of making the best possible use of daylight is now widely realised, and the design of modern buildings is determined very largely by this consideration. In older factories, however, insufficient provision for access of daylight may have been made, and in the cities the admission of light may be greatly obstructed by neighbouring buildings.

In such cases evidently, the provision of additional window space would involve costly alterations. But in scientifically designed prismatic glass the manufacturer has a simple device which can improve conditions considerably.

We have received a booklet illustrating the special glass of this kind made by Messrs. Pilkington Bros., Ltd., which is available in three distinct types for use where the angle of light is up to 30°, between 30° and 40°, and over 40° respectively. The exterior surface of the glass is flat, but the inner surface is provided with horizontal prisms which serve to direct the rays when they enter at too steep an angle, so that the light reaches the back of the room and the entire floor space is illuminated. The device is of special value in basements.

It is stated that the prismatic glass is no dearer than the better qualities of sheet glass. A point to be considered is the harbouring of dust by prisms, and it is naturally advisable that the glass should be cleaned at frequent intervals. But it is important to note that the outer surface, exposed to weather conditions and the dust of the street, is flat and easily cleaned; and the direction of light is stated to be not much affected by collection of dust on the upper sides of the prisms, as it is by the under side of the prism that the redirection of light is performed. The booklets before us contain a series of striking photographs illustrating the great improvement in illumination brought about by the substitution of prismatic glass for ordinary sheet glass. We would like to suggest that in the next edition it would be useful to include some comparative photometric measurements of the illumination at the back of the room in both cases; these would afford valuable information to lighting experts.

MAXLUME REFLECTORS.

A BOOKLET issued by Messrs. Verity's Ltd., illustrates a great variety of industrial lighting reflectors. In the introduction special emphasis is placed on avoidance of glare and a page is devoted to extracts from the reports of the Home Office Departmental Committee on Lighting in Factories and Workshops. A table showing the lumens available from standard types of lamps and the usual formula enabling illumination to be calculated are also included. It would add to the value of a future edition if particulars of the polar curves of the units illustrated could be included.

PALMER'S PUBLICITY SERVICE.

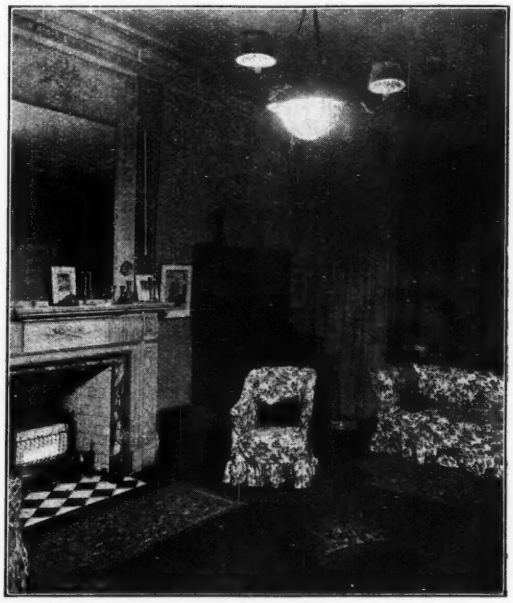
WE understand that Messrs. Palmer's Publicity Service have removed to new offices at 132–4, Fleet Street, where they now occupy the whole of the ground floor.

DOMESTIC LIGHTING WITH GAS.

A RECENT issue of *A Thousand-and-One Uses for Gas* contains some pleasing illustrations of domestic lighting, and emphasises the steady progress that has been made in the science of illumination during recent years. In the home, as in the school, good lighting is essential to the health and eyesight of children. Modern appliances, including the use of distance control switches and well-designed diffusing glassware, enable much better lighting conditions to be obtained than in the past. The accompanying illustrations show typical modern installations in the hall, drawing room and dining room.

Ceiling gas lighting with semi-opaque globe promoting even diffusion of light. The lamp is controlled by a switch near the door.

One point that is strongly emphasised is the need for satisfactory maintenance, and consumers may be advised to make use of the facilities offered by most modern gas undertakings in this respect.



A drawing room fitted with opalescent bowl and three gas "candle" burners, giving soft and diffused light.

Dining room lighted by an adjustable gas pendant and small gas burners on brackets. The pendant is lighted and extinguished by a switch near the door.

DEVELOPMENTS IN MINERS' LAMPS.

Some Notes on the Exhibits at the Mining Exhibition.

AT the recent Mining Exhibition, held at the Agricultural Hall, London, there were a number of interesting exhibits dealing with miners' lamps. Messrs. Oldham and Son, Ltd., showed their present form of pillarless lamp, which has important advantages as regards avoidance of obstruction to light and is equipped with a reflector, the adjustment of which is independent of the movement of the handle. It was also interesting to see the cap type lamp, which has distinct advantages for certain forms of work, as the liability of glare in the miners' eyes is obviated. This lamp is stated to furnish 4 candlepower at the commencement of the shift and 3·5 candlepower after nine hours, and weighs only 7 oz.; while the accumulator and steel case, strapped to the miner's belt, weighs 5 lb. 8 oz. Charging frames (for 70 and 35 accumulators) were shown in operation. Other special features include the special magnetic unlocking and bulb-removing machines, the time for the latter operation being reduced to 30 seconds as a result of the adoption of a new form of accumulator of the "snap-on" lid pattern. Yet another apparatus illustrated at this stall is the Oldham stone duster. This is primarily recommended as a safety device, which is stated to eliminate propagation of coal dust. But it is also an aid to illumination, as the lighter colour of the walls produced by stone dusting helps to diffuse the light, and improves the dead black surroundings which form one of the great difficulties in providing effective illumination in mines.

At the adjacent stall of the "Ceag" Miners' Supply Co., Ltd., we were again interested to learn that the cap form of lamp is growing in favour. We understand that arrangements have now been made to substitute one of the cheaper and simpler standard cells for the flat-plate type shown at the Exhibition. The battery is carried strapped to the waist in the usual manner and the cable is carried in a straight line with the headpiece aluminium terminating in a lamp mounted in a double convex lens secured by a screwed cap and lead rivet. There were, of course, many other standard types of lamps on view. Altogether there are five types of lamp for underground use, comprising the "Standard," "Pillarless," and three types of cap lamps. The construction of the pillarless lamp was recently described in this journal, and its advantages from the point of view of distribution of light emphasised*; it is particularly advantageous when roof-examinations have to be made.

There are also three sizes of bull's-eye lamps. The "Deputy" lamp consists of a bull's-eye lamp fitted with a torch head, and combined the advantages of both types. The "surveyor's lamp" is fitted with a cage carrying red, green, and glasses, and is equipped with a small lever enabling either colour or a white light to be shown in signalling, etc.; this lamp is entirely non-magnetic, and therefore does not affect surveying instruments. Finally there were several types of shaft lamp of substantial construction which contain four 2-volt accumulators feeding a lamp of 8 candlepower.

The "T.K." miners' lamp was on exhibition at the stall of Turquand and Kew, Ltd. The "Pearson-Nife" lamp of Alkaline Miners' Lamps, Ltd., is chiefly interesting for the special form of battery. This cell, which is of Swedish origin, utilises neither lead nor acid in its construction, the place of these materials being taken by steel, nickel and alkali. Many advantages are claimed for the cell, including lighter weight, ability to withstand high discharges and short-circuiting and very long life. It is also stated that the cells will stand for long periods either charged or discharged without suffering in any way.

Similar advantages are claimed for the nickel-iron accumulator manufactured by the Alklum Electrics, Ltd., and utilised in the Worsnop safety lamp.

Finally it is of interest to mention an ingenious method of illuminating the water-gauge of a boiler, exhibited by Messrs. Ronald Trist and Co., Ltd. The "Raybeam" device consists of a tubular lamp mounted in a metal cylinder fitting closely round the water-tube at its lower end. Light passes through a small aperture in the tube into the glass, which is lightly frosted at this point. Having entered the water the rays of light undergo total internal reflection and remain invisible until the junction of air and water is reached. Here they can escape and the meniscus of liquid accordingly appears as a highly luminous ring. The ring may be made a more prominent object by inserting a strip of tinted glass where the light enters the tube, thus giving to the ring a red colouration. It is stated that the appearance of the luminous ring is unaffected by the level of the liquid; the only effect of a longer water-column being to make the effect somewhat less bright, owing to the greater absorption.

* ILLUM. ENG., Nov.–Dec., 1922, p. 302.

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REVIEWS OF BOOKS AND PUBLICATIONS RECEIVED.

Practical Electric Light Fitting. By F. C. Allsop. (Sir Isaac Pitman & Sons, Ltd. 1923. 7s. 6d. net. pp. 288. Figs. 269.)

IN the preface it is stated that Mr. Allsop's book, when originally published in 1892, was the earliest work of this kind to appear. It has now been revised and extended and covers a wide field in a practical manner. The chapters on lamps are now up to date, reference being made to such novelties as the neon lamps and "artificial daylight." Wiring systems are dealt with in detail and the section on private installations, covering steam and gas engines, petrol engines, water turbines, etc., will be found useful. The account of wiring and such accessories as switchboards, meters, cable, etc., seems adequate and there is a liberal use of illustrations (almost one per page).

In his introductory remarks the author mentions that he has avoided the use of formulæ, treating the matter from the fitter's standpoint. One recognises the limitations of space in a work of this kind. Nevertheless, in these days fitters should know something of illuminating engineering. We think, therefore, that the author might with advantage introduce a chapter containing fuller details of the candlepower derived from the various forms of lamps which he illustrates, and some practical advice on their use to afford good illumination.

Return of Gas Undertakings in Great Britain for the Year, 1921, Part II. (H.M. Stationery Office, Imperial House, Kingsway, London. 10s. 6d. net. Post free, 10s. 11d.)

PART I. of this publication has already been issued. Part II., now available, contains particulars of the finances of undertakings and prices charged for gas. The section relating to companies' undertakings covers the calendar year 1921, in the case of local authorities the year ended March 31st, 1922. The publication contains much detailed and useful information which will, naturally, be studied closely by gas engineers.

A NEW SYSTEM OF STAGE LIGHTING.

On Thursday, March 8th, an opportunity was afforded to witness a demonstration of the Schwabe-Hasait system of stage lighting, which is being developed by the General Electric Co., Ltd., in this country and the Colonies.

The demonstration took place at St. Martin's Theatre, when Mr. Basil Dean, who is assisting the General Electric Co., Ltd., in an advisory capacity, explained the methods employed prior to the display. Briefly stated, the feature of the system is the use of an artificial horizon, on which any desired effect of light can be produced by means of flood-lights, aided by a special cloud apparatus. The aim of the lighting expert is two-fold : to illuminate the area occupied by the actors, and to produce varied effects on the artificial horizon. The latest method, while utilising the conventional lighting by battens and footlights to some extent, is based chiefly on the use of specially designed flood-lights, projectors and spot-lights—for instance, 1,500 w. gasfilled lamps mounted in special reflectors—all the desired effects being obtained by a single man manipulating a single switchboard. For the footlights indirect lighting has now been adopted. Coloured diaphragms can be inserted to produce various tints. The artificial horizon is preferably in the form of a cupola, or it may be cylindrical ; it usually consists of large movable sheets of canvas tightly stretched and stitched together. It is illuminated by a series of 1,000 w. gas-filled lamps in special housings, and superimposed over this main illumination, alterable at will as regards intensity and colour, images of clouds, etc., may be thrown on the sky by means of projectors. Masses of clouds can be set in motion across the sky, and snow and rain can be simulated.

The demonstration included the production of many remarkable effects, the change from night to dawn, the gathering of storm clouds, and the gradual diminution in brightness with the setting of the sun. Many of the effects were spectacular to a degree ; in fact, more striking than the changes that are ordinarily to be seen in nature. The possibilities of these methods are very great and should have a material influence on stagecraft.

ACETYLENE LIGHTING DEVELOPMENTS.

A perusal of some of the literature issued by Messrs. Allen Liversidge, Ltd., shows that portable forms of acetylene lamps are available in many varied forms. The flare-lights, conveniently supplied from cylinders of dissolved acetylene, are familiar, and are commonly used to facilitate building operations, etc., by night, as well as for emergency lighting at fêtes, etc. But the variety of hand lamps is perhaps less generally known. Some of these (notably the " hurricane " lamp) are specially adapted for outdoor use in view of the resistance of the stiff acetylene flame to draughts, and they should also have useful applications in those sections of mines where the presence of a flame gives rise to no danger. We notice one very compact and ingenious lamp that fits into a small case 3 in. diam. and 2½ in. deep, and can be carried in the pocket. The burner and reflector can be suspended by a hook, and any vessel or pool of water over 3 in. diam. and 4 in. deep will suffice for the immersion of the carbide-container.

Other catalogues give particulars of representative country house installations where acetylene is used. Among the advantages claimed for acetylene are the relatively white colour of the light and the ease with which the system can be adapted to decorative forms of fittings. It has been pointed out, for instance, that an acetylene flame approaches quite closely to the flame of a wax candle, so that there is little incongruity in applying imitation " candles " utilising this illuminant to antique chandeliers.

The firm also deals with petrol air gas and electric lighting plant, and can therefore regard the merits of the three systems impartially. The choice naturally depends much on local circumstances ; we understand that in many cases acetylene proves to be the cheaper system, but is less suitable for heating than petrol air gas. For a relatively large house, where expenditure on a double system is justified, a combination of electric lighting with a petrol air-gas system for heating and cooking is recommended.

We have confined ourselves in what has been said above to lighting developments, but the use of acetylene for welding operations now also constitutes an important field. We note that Messrs. Allen-Liversidge Ltd., are preparing a display of such apparatus for their stalls at the forthcoming Shipping and Engineering Exhibition to take place at Olympia during August 31st to September 22nd.